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THE INFLUENCE OF ELASTIC SPRINGS AND SPRING ORIENTATION ON THE DRAFT FORCE DURING TILLAGE OPERATION

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ABSTRACT

This paper discusses the influence of spring elasticity and spring orientation on the draft force during tillage operation. The experiments were conducted in a soil bin with the following dimensions: 1.2 m in length, 0.3 m in width and 0.4 m in depth. The soil used in this experiment was clay loam soil; the depth of the hardpan in the soil bin was 12 to 15 cm with a penetration resistance of 2.75MPa. The depth of the tillage operation was 14 to 17 cm, and the thickness of the hardpan to be tilled was 7 to 10 cm. The tillage tool was connected to a fixed structure using a semi-elliptical spring. The tillage speeds used were 0.158, 0.212 and 0.265 m/s. Two spring orientations were tested: The rear Spring Treatment (RST) orientation and Front Spring Treatment (FST) orientation. In the RST orientation, the draft force raised the elevation of the tillage tool tip, and the draft force caused the tillage tool tip elevation decrease in the FST orientation. Compared to rigid tine, the average draft force in the FST orientation increased up to 73 %, whereas a draft force reduction was found in the RST orientation.

Keywords: tillage operation, draft force, spring elasticity, spring orientation, tillage tool tip elevation.

1. INTRODUCTION

Soil compaction with a penetration resistance of 300psi or more and a soil bulk density of 1.8 g/cm^3 or more restricts root growth [1]. Soil tillage is intended to break up soil compaction to produce soil conditions and an environment favorable for crop growth by changing the soil bulk density, soil-aggregate size distribution and other soil characteristics [2]. A large draft force and high energy consumption during soil tillage are common [3, 4] but should be reduced.

It is well known that the average draft force required in soil tillage can be reduced using an oscillating tillage tool. Many researchers have noted that the oscillating tillage tool adds energy to the process [5-9]. Using this method, the required draft force will be significantly reduced. Unfortunately, the energy consumption increased significantly with this method. Yow and Smith [10] found a draft force reduction of approximately 30 % at a velocity ratio (the ratio of the maximum vibration speed of the tillage tool tip to the forward speed of the tool carriage) of approximately 2 and found that the overall power consumption increased by approximately 50 % compared to that of a non-oscillating tool.

Self-excited vibration, implemented by adding elastic springs to the tillage tool, was developed as one solution to this problem. This method has been tested experimentally [3, 11-13], and a draft force reduction of approximately 20 % was found. In these experiments, the draft force reduction was dependent on either the elasticity of the tillage tool or the elasticity of the spring that was installed in the tillage tool. This method has also been studied analytically. Soeharsono and Radite [14] found a draft force reduction of approximately 45 % when the natural frequency of the system was approximately twice the soil cutting frequency and the velocity ratio was greater than 4. Although this method has been studied both experimentally and analytically, no mechanisms for draft force reduction were discussed.

This paper discusses the influences of spring elasticity and spring orientation on the draft force of the self-excited vibration of a vibratory tine during tillage operations. The mechanism for draft force reduction, particularly for low-frequency soil cutting, is also discussed. The experiments were conducted in an indoor soil bin with the following dimensions: 1.2 m in length, 0.3 m width and 0.4 m in depth. The soil that was used in this experiment was clay loam soil; the thickness of the hardpan in the soil bin was 12 to 15 cm with a penetration resistance of 2.75MPa. The tilling depth was 14 to 17 cm, while the thickness of the hardpan to be tilled was 7 to 10 cm. The tillage tool was a chisel with inclined shank that was connected to a fixed structure using a semi-elliptical spring. The vibration of the tillage tool was caused by variations of the draft force. The tillage speeds used were 0.158, 0.212 and 0.265 m/s. Two spring orientations were used: Front Spring Treatment (FST) and the Rear Spring Treatment (RST) orientations. For the RST, the draft force raised the elevation of the tillage tool tip. In contrast, the draft force in the RST orientation caused the tillage tool tip elevation to decrease.

2. MATERIALS AND METHODS

2.1 Equipment and instrumentation

To study the effect of spring elasticity and spring orientation on the draft force, an experimental setup was developed and is shown schematically in Figure-1.

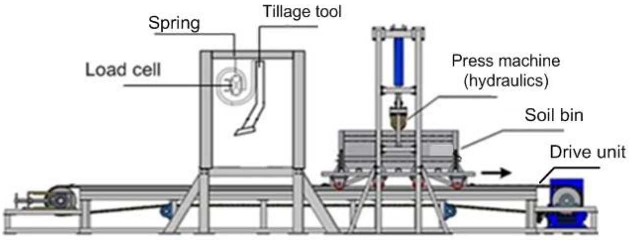


Figure-1. Lay out of the equipment setup used in the experiment.

The dimensions of the equipment were 5.5 m in length, 1.3 m in width and 2.6 m in height. The primary components were the soil bin, the hydraulics press machine, the drive unit, the elastic spring, the load cell and the tillage tool. The soil bin was 1.2 m in length, 0.3 m in width and 0.4 m in depth. The drive unit was powered by a 5.5 kW electric motor that was used to drive the soil bin. The power from the electric motor was transmitted to the drive chain in the drive unit using a gearbox with a gear reduction of up to 40. The drive unit was equipped with an inverter that varied the velocity of the soil bin from 0.1 to 0.68 m/s. The hydraulic press machine was used to compact the soil in the soil bin, had a capacity of up to 7000 N and had the ability to compact the soil in the soil bin up to a penetration resistance of 3 MPa. The load cell was an Extended Octagonal Ring (EOR) transducer and had a sensitivity to measure force in the vertical direction S_V of approximately 5.722E-05 (mV).$V^{-1}N^{-1}$ and sensitivity in the horizontal direction S_H of approximately 5.552E-05 (mV).V^{-1} N^{-1}. Cross sensitivities in the horizontal-vertical direction (S_{HV}) and in the vertical-horizontal direction (S_{VH}) were so small and could be neglected. The material of the EOR transducer was alloy steel and was prehardened to yield strength of approximately 680MPa. The elastic spring was a new model produced from S55C steel and prehardened to yield strength of approximately 550MPa. The stiffness of this spring was 28602 Nm/rad, and it had the ability to vibrate in the vertical and horizontal directions. The tillage tool was a chisel with inclined straight shank that had an incline angle of approximately 35^0 and a rake angle of approximately 30^0.

The instrumentation used to collect the force measurements is shown in Figure-2. The draft force was measured using an EOR. The analog signals from the EOR were amplified using an instrumented amplifier and then converted to a discrete signal using a wireless analog to digital converter. Therefore, the signal recorded by the computer was a discrete force signal.

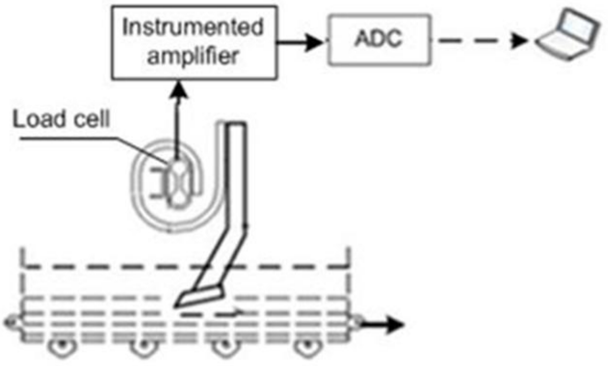
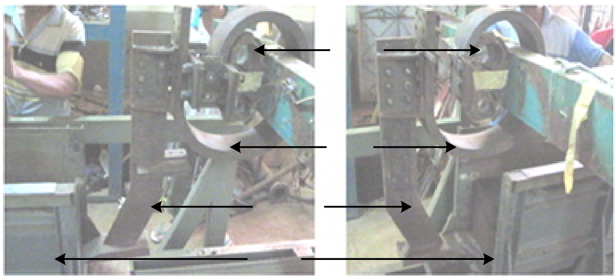


Figure-2. The instrumentation used to collect the draft force measurements.

2.2 Test description and procedure

The experiments were conducted from May to December 2010 in an indoor soil bin located at the Agricultural Machinery Laboratory in the Mechanical and Bio system Engineering Department, Bogor Agricultural University. There were twoo spring orientations (the FST and RST orientations) and one Non Spring Treatment (NST) for tillage operations. The NST provided non-vibratory tillage on the tine. In this treatment, the elliptic spring was not installed. The FST and RST orientations were self-excited vibration-vibratory tillage. The details of these treatments are shown in Figure-3. For the FST orientation, the tillage tool tip was directed to the left, while the soil bin was shifted from left to right. For the RST orientation, the tillage tool tip was directed to the right, while the soil bin was shifted from right to left. For the NST and RST orientations, the tillage speeds used were 0.158, 0.212 and 0.265 m/s; for the FST orientation, the tillage speed was 0.158 m/s.



(a) (b)

Figure-3. The two spring orientations for the tillage operation: (a) the FST orientation and (b) the RST orientation.

The soil used in this experiment was clay loam soil that consisted of 83.4 % clay, 3.1 % sand and 13.5 % silt. The soil liquid limit was 70.3%, and the soil plastic limit was 45.5 %. The soil in the soil bin was divided into two layers, as shown in Figure-4.

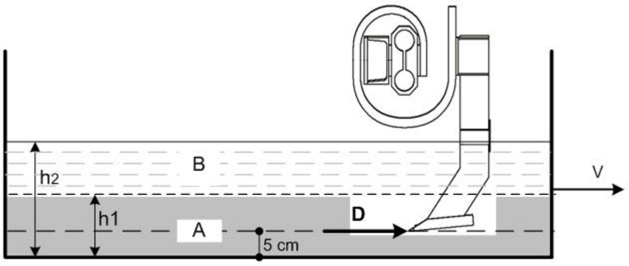


Figure-4. The two layers of soil in the soil bin.

The details of the soil parameters are listed in Table-1. The A layer simulated hardpan with a soil density of approximately 1.56 g/cm^3, a soil penetration resistance of approximately 2.75 Mpa and soil moisture content 35-36 %. The B layer simulated top soil and had a soil penetration resistance of approximately 1.1 MPa. The thickness of the hardpan for the NST and RST orientations was 15 cm and the thickness of the hardpan to be tilled was 10 cm. The thickness of the hardpan for the FST orientation was 12 cm, and the thickness of the hardpan to be tilled was 7 cm.

Table-1. Details of the soil parameters used in the experiments (see Figure-4).

Treatment	**Soil layer thickness in the soil bin** (cm)		**Penetration resistance** (MPa)	
	h1	h2	A	B
NST	15	22	2.75	2.4
RST	15	22	2.75	1.1
FST	12	19	2.75	1.1

3. RESULTS AND DISCUSSIONS

3.1 FST orientation

Figure-5 shows the graphs of the draft force as a function of time for the FST and NST. Details of the soil parameters for this treatment are shown in Table-1.

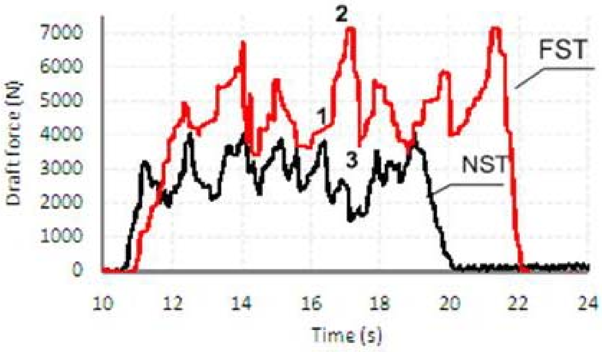


Figure-5. Graph of the draft force due to the FST and NST: tillage speed = 0.108 m/s.

Figure-5 shows that the draft force for the vibratory tillage present in the FST orientation was higher than that for the non-vibratory tillage present in the NST, despite the thinner soil layer in the NST. For the NST, the maximum draft force was 3850 N and the mean draft force was 2843 N. For the FST orientation, the maximum draft force was 7050 N, and the average draft force was 4937 N. Therefore, the FST orientation caused an increase of approximately 73 % in the average force and an increase of approximately 83 % in the maximum draft force. This phenomenon can be explained as follows: the soil cutting force deflected the tillage tool backwards and lowered the elevation of the tillage tool tip (Figure-6). This condition caused the depth of the tillage operation to deepen; therefore, the draft force resulting from the FST orientation was larger than that of the NST.

The strength in the spring was tested using the AutoDesk Inventor software. For a draft force of approximately 7200 N, the equivalent stress in the elastic spring was 530 MPa, which was close to the yield strength of the spring. To avoid yielding in the steel of the spring, this FST orientation could not be repeated for an additional experiment, particularly if a higher tillage speed was tested.

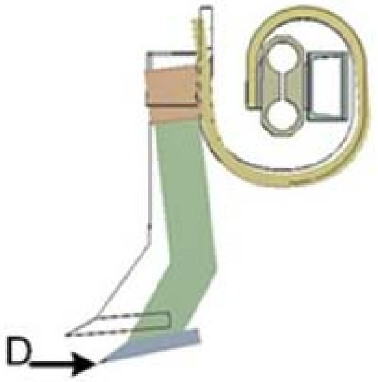


Figure-6. The displacement of the tillage tool in the FST orientation due to draft force D.

3.2 RST orientation

The draft force graph of the results of the RST and NSTs is shown in Figure-7. In this case, both the RST orientation and the NST utilized the same soil parameters, as shown in Table-1. The hardpan thickness was 15 cm, the thickness of the hardpan to be tilled was 10 cm and the tillage depth was 17 cm. Figures-7a, 7b and 7c are graphs of the draft forces due to the RST and NST tillage orientations with tillage speeds of 0.158, 0.212 and 0.265 m/s, respectively. The numerical data for the NST and FST orientations is shown in Table-2. The average draft force reductions due to the tillage speeds of 0.158, 0.212 and 0.265 m/s were 23.64 10.64 and 18.15 %, respectively, while the maximum draft force reductions were 19.87, 15.56 and 15.17%, respectively. The mean of the average draft force reduction was 16.87%, while the mean maximum draft force reduction

Table-2. Draft force comparison of the NST and RST tillage orientations.

Tillage speed (m/s)	**Description**	**Draft force** (N)		**Draft force reduction** (%)
		NST	**RST orientation**	
0.158	Maximum	3965	3177	19.87
	Average	2880	2199	23.64
0.212	Maximum	3990	3369	15.56
	Average	2556	2284	10.64
0.265	Maximum	4732	4014	15.17
	Average	3245	2656	18.15

was 17.48%. Both the graphs in Figure-7 and the numerical data in Table-2 show that the draft force of the RST orientation was less than that of the NST. This indicates that proper installation of the elastic spring in self-excited vibration-vibratory tillage will reduce the draft force required during tillage operations.

The phenomenon of decreasing draft force can be explained by the following:

- During the forward motion of the soil bin, the tillage tool pressed against the dense soil, and high resistance was encountered. This pressure caused the tillage tool to be displaced (Figure-8), and the energy was stored as strain energy in the spring. At the time of soil break-up, the soil resistance became low and the stored energy of the spring returned the tillage tool to its original position at a high speed. The impact between the tillage tool tip and the dense soil resulted in cracks in the soil and degraded the penetration resistance.
- The soil cutting force deflected the tillage tool backwards and increased the elevation of the tillage tool tip. This condition caused the depth of the tillage operation to become lower, thereby decreasing the draft force.

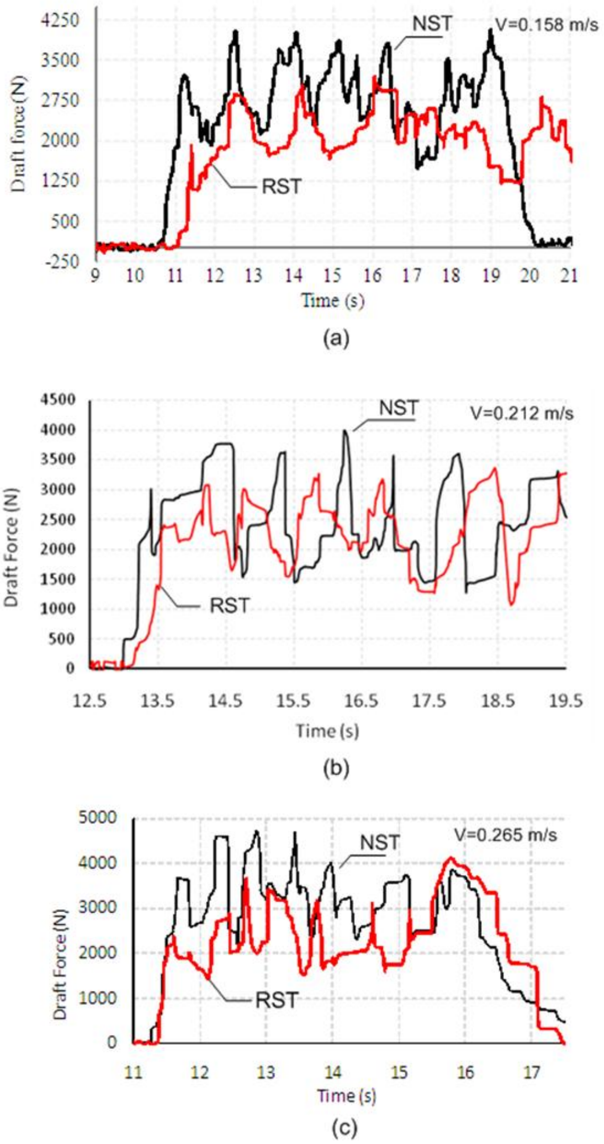


Figure-7. Graphs of the draft force due to the RST and NST: (a) tillage speed = 0.158 m/s (b) Tillage speed = 0.212 m/s and (c) tillage speed = 0.265 m/s.

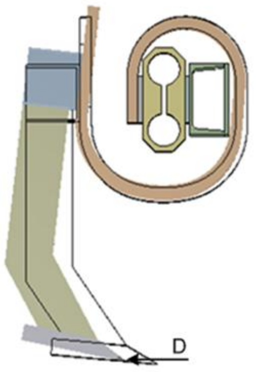


Figure-8. The displacement of tillage tool in the RST orientation due to draft force D.

4. CONCLUSIONS

This study to determine the influences of the spring elasticity and orientation to draft force was conducted in an indoor soil bin. The spring stiffness was found to be 28602 Nm/rad. The soil was clay loam consisting of 83.4 % clay, 3.1 % sand and 13.5 % silt. Two spring orientations were used: the FST and RST orientations. Compared to the average draft force on rigid tine, that is in the FST was increased up to 73 %, whereas the average draft force reduction was approximately 17.48 % in the RST orientation. The important conclusions from these results are as follows:

- For the FST orientation, the draft force was excessively increased, and this arrangement is not recommended for application.
- For the RST orientation, the draft force reduction were found, therefore RST arrangement is recommended for application

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