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PERFORMANCE OF AN OSCILLATING SUBSOILER IN BREAKING HARD PAN

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ABSTRACT

Field experiments were conducted to determine the optimum combination of performance parameters of a single-shank, tractor-mounted oscillating subsoiler. Tests were conducted at frequencies of oscillation of 3.7, 5.67, 7.58, 9.48 and 11.45 Hz; amplitudes of 18, 21, 23.5, 34, and 36.5 mm; and forward speeds of 1.84, 2.19 and 3.42 kmph at moisture content close to the plastic limit of the soil.

It was observed that there was a reduction in average draft but an a increase in average total power requirement for oscillating than non-oscillating subsoiling. The draft and power ratios were significantly affected by the forward speed, frequency and amplitude. Their combined interaction expressed in terms of the velocity ratio parameter (the ratio of peak tool velocity and forward speed) however has the strongest influence. At the same velocity ratio, the draft reduction and power increase were less at higher amplitude of oscillation. As the oscillating frequency is increased towards the soil resonance the draft requirement becomes less. For the field conditions tested, the optimum operation was obtained at an amplitude of 36.5 mm, frequency of 9.48 Hz and speed of 2.19 kmph with a draft ratio of 0.33 and a power ratio of only 1.24.

Key Words: Subsoiler, oscillating, tillage, draft and power

INTRODUCTION

Many types of soils are susceptible to compaction and formation of impermeable hard pans below tillage depth. On moist, tilled sandy soil, Goolsby and Seigler (1976) and Trouse (1979) as cited by Hammond et al. (1981) reported that two to five cm thick layer of these pans are formed quite easily after a few trips by tillage machines. Hard pans inhibit root penetration and cause drainage problems which result in reduced crops yields. In Thailand, problems of soil compaction and hard layer formation are common in sugarcane farms especially after harvest when heavy trucks transport the cut canes from the field to the sugar factory. The fields are subsoiled annually to break through and shatter these soil layers to improve drainage for the next crop (Niyamapa, 1991). The utilization of tractor PTO power for tillage is not common among Thai farmers and subsoiling is done conventionally thus requiring very high draft and hence tractor ballasting which consequently results in recompaction.

Vibration of soil engaging tools like blade, tine or share has been known to reduce the draft force needed to pull the implement and this is highly desirable in high draft implements such as subsoilers. Draft reduction has been studied and verified by many researchers including Gunn and Tramontini (1955); Hendrick et al. (1963); Larson (1967); and Smith et al. (1972). The use of vibration in tillage also produces better soil breakup, although the total power requirement may not be reduced (Johnson & Buchele, 1969; and Smith et al., 1972). However, for a certain degree of pulverization, the total energy input per unit mass will be smaller compared to non-vibratory tillage since secondary tillage is minimized (Larson, 1967). With the reduction in draft for soil cutting using vibratory tillage, it is therefore possible to work on deep and difficult task with high draft requirements such as subsoiling. In addition it is also possible to use light tractors with considerable power thus soil compaction can be minimized.

Vibratory tillage has been studied extensively throughout the world but most of the research efforts were directed towards discovering how soil properties are influenced by oscillating tool and how is it possible to develop implements which can stand up to heavier stresses imposed upon them by oscillation without jeopardizing cost. These studies were done mostly under laboratory conditions using model tools. However, Niyamapa (1992) recently developed an actual size, a single-shank oscillating subsoiler intended for the use of sugarcane farmers in Thailand. Preliminary investigations showed that it may quite well be adaptable locally under certain operating conditions.

The objective of this study was to test the performance of this oscillating subsoiler under actual field conditions and to establish its optimum operating parameters. Specifically, the study was conducted to:

1. Determine the draft and total power required for soil break-up of the vibratory subsoiler at different amplitudes, frequencies of oscillation, and forward speeds; and
2. Determine the optimum combination of amplitude of oscillation, vibration frequency, and forward speed in terms of draft and total power requirement.

MATERIALS AND METHODS

Description of Test Site

The experiments were conducted in the field of the Kasetsart University, Khampaeng Saen campus, Nakorn Pathom, Thailand. An idle sugarcane field of one hectare which had already been used as aprons for trucks that load sugarcane was used for field testing. It contains clay having a liquid limit of 28 percent, plastic limit 22 percent, cohesion 19.15 kPa, adhesion 3.99 kPa and angle of internal friction of 31.4°.

The average cone index in the area was 1,414 kPa but the soil strength varied within the boundaries. Hence the area was divided into three (3) blocks having cone indices ranges of 1,352 to 1984 kPa (average 1,669 kPa) for the first block; 996 to 1,765 kPa (average 1,422 kPa) for the second and 799 to 1,675 (average 1,150 kPa) for the third block.

The bulk density of the soil was determined along the soil profile at every 15 cm to 45 cm deep. The average densities were 14.6 kN/m^3 at the first 15 cm, and 15.5, 15.2, 153 kN/m^3 for the 15-30 cm, 30-45 cm and 45-60 cm, respectively Moisture contents of the surface soil varied during the test from 8 to 21.15 percent and second layer from 9 to 27 percent. However, the moisture conditions near the operating depth of 45 cm was relatively constant varying from 18 to 22 percent.

Test Machine and Instrumentation

The schematic diagram of the oscillating subsoiler is shown in Fig. 1. The share attached at the bottom of the standard is 400 mm long having a cutting edge of 70 mm and a lift angle of 30° as recommended by Sakai et al. (1983). Oscillation is accomplished through an eccentric shaft connected to the upper end of the share so that it is moved forward and backward. The amplitude was varied from 18, 21, 23.5, 34, and 36.5 mm by replacing the crank shaft of different eccentricities.

Power was transmitted to the crankshaft from the tractor PTO through a pair of spiral-bevel gears having a speed reduction of 3.75 and to a sprocket and chain with a ratio that can be varied depending on the desired frequency and the PTO speed. To minimize forward speed variation, the engine speed was set to give 540 PTO rpm during the test and the frequency was varied by changing sprocket combinations. The desired frequencies of 3.7, 5.67, 7.58, 9.48 and 11.45 Hz were obtained by using the sprocket combinations with speed reductions of 2.25, 1.5, 1.125, 0.9 and 0.75, respectively. Average forward speeds of 1.84, 2.19 and 3.42 kmph were obtained by selecting different gear positions. The tractor used was a 43-kW KUBOTA model 5500DT. Fig. 2 shows the subsoiler mounted on an instrumented tractor in operation during the experiment.

The instrumentation system included measurement of forces in the

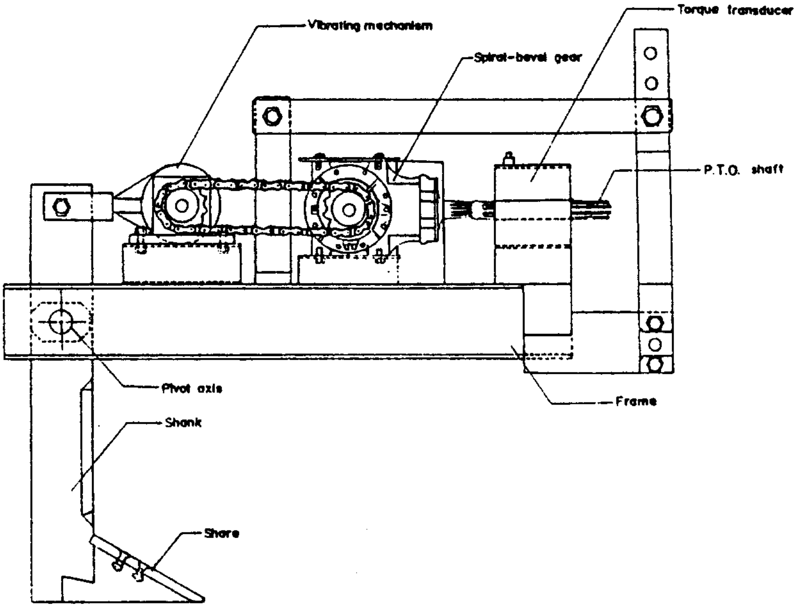

Fig. 1. Schematic diagram of oscillating subsoiler (Niyamapa, 1992).

Fig. 2. The subsoiler in operation during the test.

connecting links, torque, rpm, operating depth and angle of inclination of the upper link. For the strain gaged transducers, a six-channel auto-balancing KYOWA strain amplifier (Model DPM-311A) was used to amplify the signals. All measurements were recorded on a seven channel SONY magnetic tape recorder (DFR-3715) for further analysis.

A strain gaged torque meter (NIKKIE, Japan) attached to the PTO shaft from the gear box measured the torque while an electromagnetic pick-up measured the PTO rpm. The draft and lift forces were measured using the technique suggested by Kawamura et al. (1987). This was done by bonding four strain gages at each of the two lower link pins and the upper link. The draft and lift forces were determined by bending the lower link pins and axial loading of the top link. The inclination of the upper link was measured by a rotary potentiometer attached at the pivot of the tractor lift arm. This potentiometer also measured the depth of subsoiling. The average depth of operation was found to be 46 cm.

In order to establish local soil resistance, non-oscillating draft was randomly obtained at frequent intervals.

Data Analysis

The analog data stored in the magnetic tape recorder were converted to digital form through a 16 channel ADU (MOWLEN Microsystems) at the rate of 128 readings per sec per channel. A special program was written in Advanced BASIC to transfer data into the microcomputer for further processing by LOTUS22. The average draft and power was determined by integrating the representative portion of the data samples of a test record. A GRAPHTEC DT1000 digitizer was used to integrate the time history of the representative samples and a program in Advanced BASIC was also written to determine the area under the curve within the time domain.

Statistical analysis of the data was made using the STATGRAPHICS Release 4 software. The experiment was laid out in a 3 x 5 x 5 factorial in Randomized Complete Block Design with three replications and analyses of variance were made on the draft reduction and power increase.

Resonance frequency

Laboratory experiment was conducted to determine the resonance frequency of a cylindrical soil sample from the test site. The technique used by Gupta and Rajput (1982) was adopted in determining the resonance frequency. An apparatus similar to the electrodynamic mechanical tester was fabricated for this purpose. The soil sample was clamped in the center and one of its faces was excited by a vibrating needle. Stress waves propagated on both faces of the sample were picked-up by accelerometers and the signals were suitably amplified. The output were read in the oscilloscope. Resonance occurred when a circular Lissajous figure was formed on the display and the frequency at this condition was the resonant frequency.

The average frequency at resonance for the samples tested was found to 18.4 Hz.

RESULTS AND DISCUSSION

The performance of the subsoiler was expressed in terms of the dimensionless draft and power ratios. These ratios were obtained by dividing the average draft and power requirements for the subsoiler with oscillation by the average draft and power without oscillation at the same forward travel speed. Figs. 3 and 4 show the relations of draft ratio and power ratio, respectively at different frequencies, amplitudes and forward speeds. As shown, the draft ratio generally decreased and the power ratio increased with an increase in frequency. This holds true for all amplitudes and forward speeds tested. For the same frequency and forward speed, higher amplitudes tended to give less draft ratio and higher power ratio although it does not hold true all the time especially at low speed. As shown in Fig. 3a, at an amplitude of 34 mm the draft ratio is suddenly changed from 0.72 to 0.36 as the frequency is increased from 3.7 to 5.66 Hz and then becomes relatively constant at draft ratios less than at 36.5 mm amplitude. Also, increasing the speed seemed to minimize the draft reduction and power increase for the same frequency and amplitude. However, at lower frequency the power ratio increased with an increase in forward speed. The power ratio increases fast at lower speed and higher frequency.

Statistical analysis revealed that the frequency, amplitude and forward affect significantly the draft ratio and power ratio. The analysis also revealed that combined interaction of these three parameters has the highest significant effect on the draft and power ratios. This is generally expressed in terms of the velocity ratio represented by λ

$$\lambda = \frac{2\pi f a}{V_o} \qquad (1)$$

where f = oscillating frequency, Hz
a = displacement amplitude, m
V_o = forward velocity, m/sec

The effect of velocity ratio on the draft ratio and power ratio at different amplitudes is shown if Figs. 5 and 6. As the velocity ratio increases the draft ratio generally decreases while the power ratio increases. At the same velocity

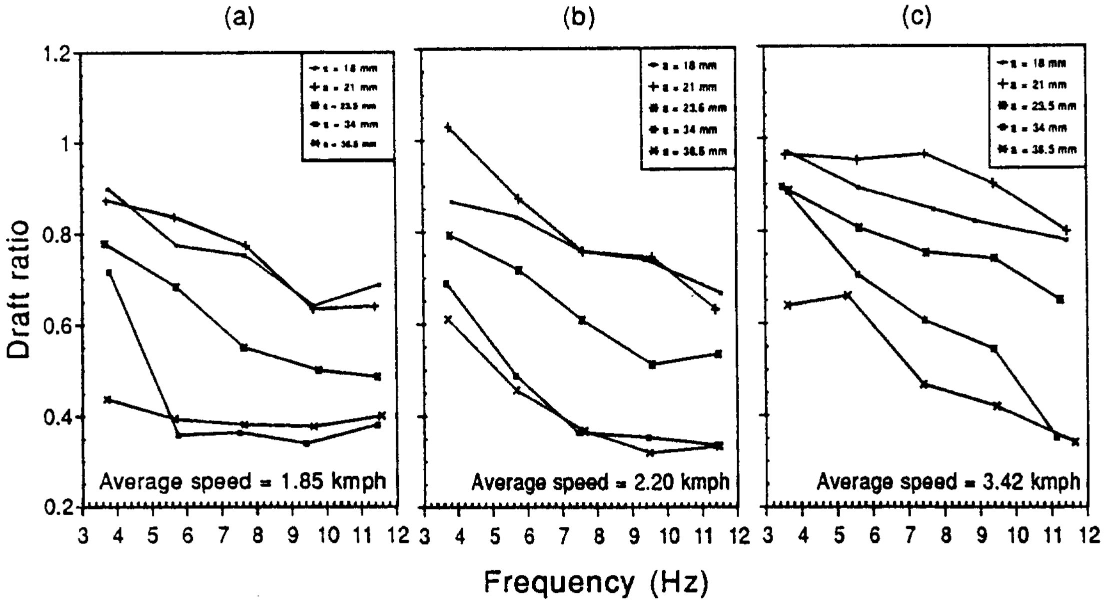

Fig. 3. Effect of frequency, amplitude and forward speed on the draft ratio.

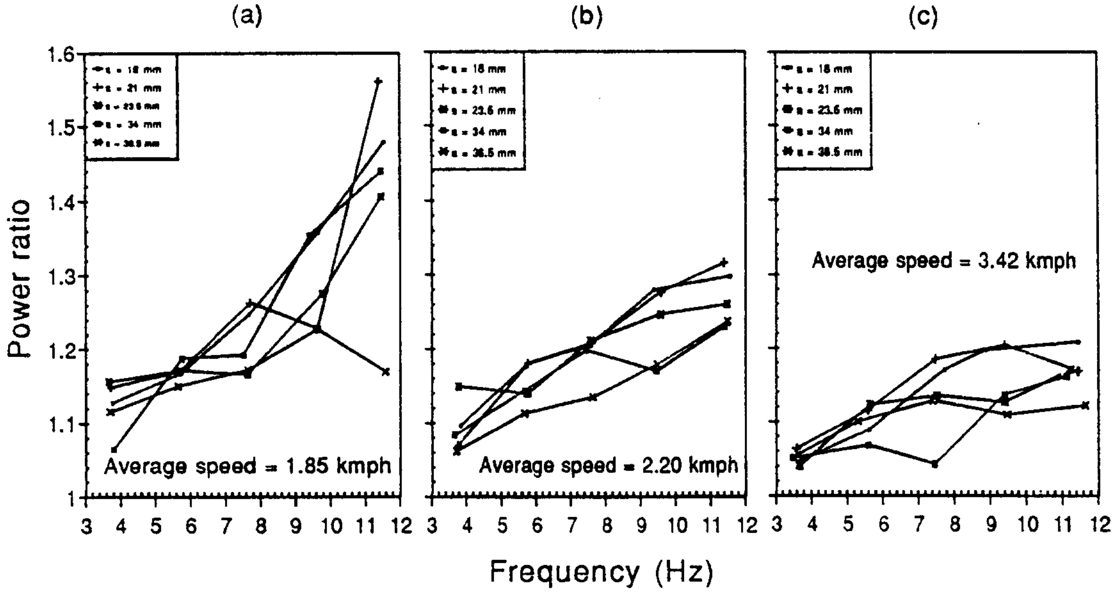

Fig. 4. Effect of frequency, amplitude and forward speed on the power ratio.

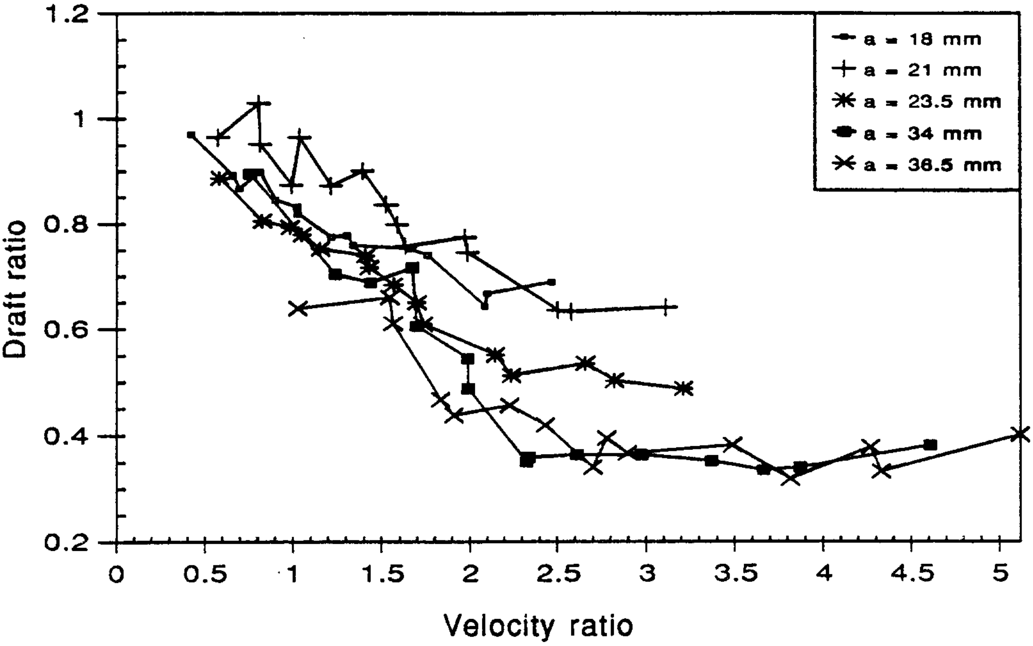

Fig. 5. Effect of velocity ratio on the draft ratio at different amplitudes of oscillation.

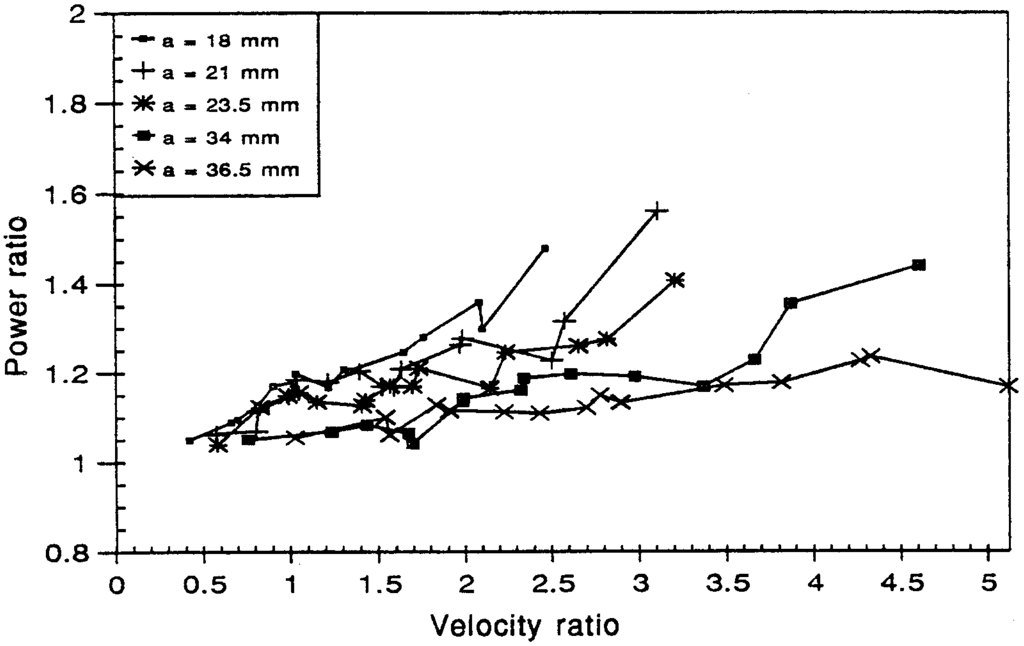

Fig. 6. Effect of velocity ratio on the power ratio at different amplitudes of oscillation.

ratio, the draft reduction and power increase were less at higher amplitude.

By comparing the performance subsoiler at different operating parameters, it was revealed than an amplitude of 36.5 mm, frequency 9.48 Hz and forward speed 2.19 kmph gave a better draft reduction 0.33 with a power increase of only 1.24.

CONCLUSIONS

Based on the results of the study, the following conclusions were drawn:

1. The oscillating subsoiler requires less draft but higher power than non-oscillating subsoiler.

2. The draft ratio decreases and the power ratio increases at higher velocity ratio.

3. The implement cannot be operated at frequencies lower than 5 Hz because of riding discomfort on the part of the operator. Sakai et al. (1993) reported that the tractor-implement system has fundamental frequency range of 3-5 Hz.

4. It is better to operate the subsoiler at frequencies near the fundamental frequency of the soil.

5. It is difficult to obtain a very optimum combination of the operating parameters of the subsoiler in actual field situation because the velocity ratio is the one that determines optimum performance. In the field the slip cannot be controlled and each soil condition has a different fundamental frequency.

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