ISSN 0858-2114

International Agricultural Engineering Journal

CONTENTS

Vol. 19, No. 1, 2010

Research Papers:

Published by

THE ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING (AAAE)

International Agricultural Engineering Journal

An International Journal on Research and Development in Agricultural Engineering
Published by the Asian Association for Agricultural Engineering (AAAE)

INTERNATIONAL

AGRICULTURAL ENGINEERING

JOURNAL

Published by

ASIAN ASSOCIATION FOR AGRICULTURAL ENGINEERING (AAAE)

Vol. 19, No. 1, 2010

Aims and Scope: The aim of this journal is to communicate advances in Agricultural Engineering, with particular reference to Asia, to practicing professionals in the field. The scope will include soil and water engineering, farm machinery, farm structures, post-harvest technology, biotechnology food processing and emerging technologies. Subjects of general interest to agricultural engineers such as ergonomics, energy, systems engineering, precision agriculture, protected cultivation, terramechanics, instrumentation, environment in agriculture and new materials are also included.

Publication Schedule: International Agricultural Engineering Journal is published in four issues per year.

Subscriptions: For academic institutions, the annual subscription is US$ 150 per calendar year. The journal copies will be mailed by air mail.

Correspondence: All manuscripts and other correspondence should be directed to the Dr. Wang Yingkuan, Executive Editor-in-Chief, Chinese Academy of Agricultural Mechanization Sciences, Beijing, 100083, E-mail: wangyingquan@gmail.com

Experimental investigation on the application of vibration to reduce draft requirement of subsoiler

P. A. S. Radite, W. Hermawan, Mulyana, A.B. Rizkianda, H.B. Crosby

(Laboratory of Farm Machinery, Department of Agricultural Engineering, Faculty of Agriculture and Technology, Bogor Agriculture University, Bogor 16610, *Indonesia)*

Abstract: This paper presents the application of vibration to reduce subsoiler draft. In this research, two different techniques of induced vibration were used. The first was the oscillated subsoiler shank technique, and the second was the oscillated subsoiler wing technique. Two different mechanisms of wing oscillation were tested: one was a design which placed a connecting rod behind the subsoiler shank, and the second was a design which placed a connecting rod in front of the subsoiler shank. All of the three developed vibratory subsoilers were very unique in design and worked satisfactorily during field tests. The results of the test showed that the shank oscillation technique or directly vibrated subsoiler shank on the vibratory subsoiler could reduce draft up to 60%. This draft reduction was about 20% higher than that of the wing oscillation technique, in which the induced vibration was acting upon the subsoiler wing while the shank remained fixed. However, wing oscillation greatly minimized the tractor's body vibration as compared to the shank oscillation technique.

Keywords: vibratory subsoiler, shank oscillation, wing oscillation, power take-off driven

Citation: Radite, P. A. S, W. Hermawan, Mulyana, A. B. Rizkianda and H. B. Crosby. 2010. Experimental investigation on the application of vibration to reduce draft requirement of subsoiler. International Agricultural Engineering Journal, 19(1): 31−38.

1 Introduction

The use of vibration to minimize resistance of soil working implements dates back to the 1950s. Gunn and Tramontini (1955) pioneered research on the application of vibratory techniques on soil working implements when they worked on the oscillating cultivator. Their results then inspired many researchers to explore more techniques for practical application.

It has been reported in many works that the effectiveness of vibration to reduce draft was dependent on a proper combination of frequency, amplitude and forward speed of the implement, or strictly speaking, dependent on the ratio of velocity of oscillated share to traveling speed of the implement. This ratio is known as the velocity ratio. If velocity ratio (=β) is greater than 1, this method can work (Gun and Tramontini, 1955; Butson and MacIntyre, 1981; Al-Jubouri and McNulty, 1984; and others). On his experimentation with vibrating tine on wet soil in soil bin, Dubrovskii (1956) reported that if forward speed increased, then the longitudinal size of un-pulverized soil which was pushed upward was increased, and if the tine was oscillated at a wavelength shorter than the longitudinal size of un-pulverized soil, then soil pulverization was improved and the required force was decreased.

Up to the present date, research topics on vibratory soil working implements still attract many researchers to investigate their potential benefit. Working on a vibratory potato digger operated at an amplitude of 10-25 mm at frequency of oscillation between 7.5 Hz and 18 Hz and speed of 3.0 km/h, Al-jubouri and McNulty (1984) reported that up to 50% draft reduction could be achieved at velocity ratio greater than 2. However, several researchers reported that reduction in draft had the drawback of an increase in total energy consumption as

Received date: 2009-06-13 **Accepted date:** 2010-03-20
Corresponding author: P. A. S. Radite, Phone: +62-251624622, mobile 62-81513124126, e-mail: iwan_radit@yahoo.com

the implement was oscillated. On investigation of the chisel model in soil bin operated at an amplitude of 8 mm at frequency of oscillation of about 50 Hz and forward speed between 0.54 km/h and 1.98 km/h, Butson and McIntyre (1981) reported that at velocity ratio greater than 3.0, draft could be reduced as much as 50% but total power could increase up to four times.

Niyamapa and Salokhe (2000) also reported that application of vibration could reduce the draft of tillage tools. Using a V-shaped share fixed on an oscillating shank, it was reported that the draft ratio of oscillating to non-oscillating mode varied from 63% to 0.93%, but the total power required for oscillating operation increased to 41%-45% more than the power required for non-oscillating operation. Using a full-scale prototype of a single shank subsoiler, Bandalan et al. (1999) also found that increased velocity ratio resulted in a lower ratio of draft. After comparing the performance of the subsoiler at different operating parameters, it was concluded that an amplitude of 36.5 mm, frequency of 9.48 Hz and forward speed of 2.20 km/h gave the lowest draft ratio (0.33), with a power increase factor of only 1.24 over non-oscillating operation.

In this research, a subsoiler was used. The subsoiler was a soil working implement intended to break soil hardpan in order to reduce soil compaction, especially in sugar cane fields. At this moment, the main concern of research is limited to reduction of subsoiler draft. It is understood that applying oscillation will undoubtedly increase total power, as has been reported by many researchers (Butson and McIntyre, 1981; Bandalan, et al, 1999 and Niyamapa and Salokhe, 2000). However it is also well known that not 100% of engine power can be transformed and delivered as drawbar power. Brake horsepower to draw bar power transformation is limited by tractive efficiency. Tractive efficiency, the ratio of drawbar power to axle power, depends mainly on soil conditions, tires, and amount of weight on the tires. For two-wheel-drive tractors on firm soil, tractive efficiency is less than 78% (at 10% slip) and even decreases to less than 65% (at 12% slip). Therefore, we have to utilize part of the engine power that is potentially available through the tractors' power take-off (PTO) power. In other words, PTO power could be utilized for generating oscillation on vibratory soil working implements (Taylor, Schrock, and Wertz, 1991).

This research is therefore conducted with the main concern of finding a practical design of vibratory subsoiler, which is not only able to reduce its draft requirement but also to minimize transferred vibration to the body of the tractor.

2 Materials and methods

2.1 Description of field tests

Field tests were conducted at the experimental station of the Department of Agricultural Engineering, Bogor Agriculture University at Leuwikopo Bogor. Half a hectare of land was used to carry out experiments. The soil texture at depth of 0-40 cm consists of 8.3% sand, 13.7% silt and 78.0% clay, which is classified as clay soil according to USDA classification.

When the prototypes of shank oscillation vibratory subsoiler were tested at Leuwikopo field, the range of soil moisture content at a depth of 0-40 cm was between 44.7% d.b. and 48.4% d.b., with an average value of 46.1%. The average soil cone index at a depth of 0-10 cm was 1,860 kPa; at 10-20 cm, 2,105 kPa; at 20-30 cm, 1,811 kPa; and at 30-40 cm, 2,173 kPa.

When prototype I of the wing oscillation vibratory subsoiler was tested at Leuwikopo field, the range of soil moisture content at a depth of 0-40 cm was between 32.2% d.b and 44.7% d.b, with an average value of 37.4%. The average soil cone index at a depth of 0-10 cm was 1,864 kPa; at 10-20 cm, 2,020 kPa; at 20-30 cm, 1,962 kPa; and at 30-40 cm, 1,453 kPa.

When prototype II of the wing oscillation vibratory subsoiler was tested at Leuwikopo field, the range of soil moisture content at a depth of 0-40 cm was between 21.8% d.b and 28.7% d.b, with an average value of 24.6%. The average soil cone index at a depth of 0-10 cm was 1,746 kPa; at 10-20 cm, 2,031 kPa; at 30-40 cm, 1,874 kPa; and at 20-40 cm, 1,423 kPa.

Field tests were also conducted at a sugar cane plantation at Jatitujuh, Majalengka. The soil texture at Jatitujuh field at a depth of 0-40 cm consists of 29.2% sand, 36.5% silt and 34.3% clay, which is classified as clay loam soil according to USDA classification. However, soil harness in Jatitujuh field was much heavier than soil harness at Leuwikopo field, as indicated by its soil cone index. In detail, the cone index on each depth of both fields is presented in Table 1.

Table 1 Cone index of tested field

Depth /cm	Cone Index/kPa			
	Jatitujuh field			Leuwikopo field
	Plant cane	1st ratoon	3rd ratoon	
0-5	1,088	951	1,009	343.0
5-10	1,186	1,166	1,470	607.6
10-15	1,323	1,480	1,784	735.0
15-20	1,490	1,568	2,097	1176.0
20-25	1,568	OV	OV	1479.8
25-30	OV	OV	OV	1558.2
30-35	OV	OV	OV	1519.0
35-40	OV	OV	OV	1274.0
40-45	OV	OV	OV	1372.0
45-50	OV	OV	OV	1352.4
50-55	OV	OV	OV	1323.0

Note : Cone index was measured using SR-2 penetrometer, using a 2 cm^2 cone; OV : cone index > 2,450 kPa.

2.2 Prototypes

The prototypes tested represented three different designs on the application of vibration technique in order to reduce draft on subsoiling operation. The first prototype was a dual row subsoiler with a tilted straight shank equipped with shank vibrated mechanism. The second and third prototypes were also dual row subsoilers with curved parabolic shank shape equipped with wing vibrated mechanism. All prototypes were designed to have the ability to work on depth of more than 40 cm.

All the prototypes used tractor PTO power as a power of rotation. On the first prototype, oscillation was accomplished through a double crank and rocker mechanism. As illustrated in Figure 1, the first crank and rocker mechanism consisted of a space eccentric cylinder and connecting rod. This mechanism was intended to change the direction of motion from the PTO axle to the axle of the second crank and rocker mechanism. With this mechanism, a complete rotation of the PTO axle gave two complete cycles of shank oscillation. Amplitude of oscillation was defined as horizontal movement of the tip-end of the subsoiler foot. Only two variations of amplitude were provided: 52 mm and 63 mm at frequency between 8.4 Hz and 16.0 Hz. The tests were carried out at speeds between 2.2 km/h and 3.9 km/h.

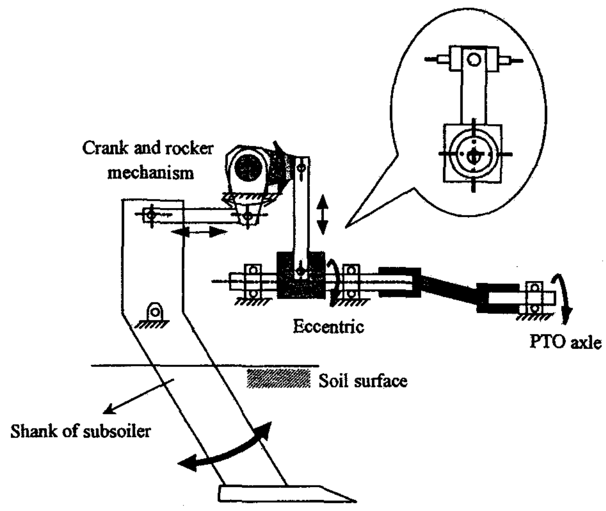


Figure 1 Double crank and rocker mechanism to oscillate the shank of subsoiler

On the second prototype, oscillation was accomplished through an eccentric crank and rocker mechanism, as illustrated in Figure 2. This mechanism used gear box transmission of ratio 1:1 to change the direction of motion from the PTO axle to the axle of eccentric crank. With this mechanism, a complete rotation of the PTO axle gave one complete cycle of wing vibration. Only two variations of amplitude were provided: 64 mm and 73 mm at frequency 7.3 Hz to 13.2 Hz. The tests were carried out at speeds between 1.7 km/h and 2.3 km/h.

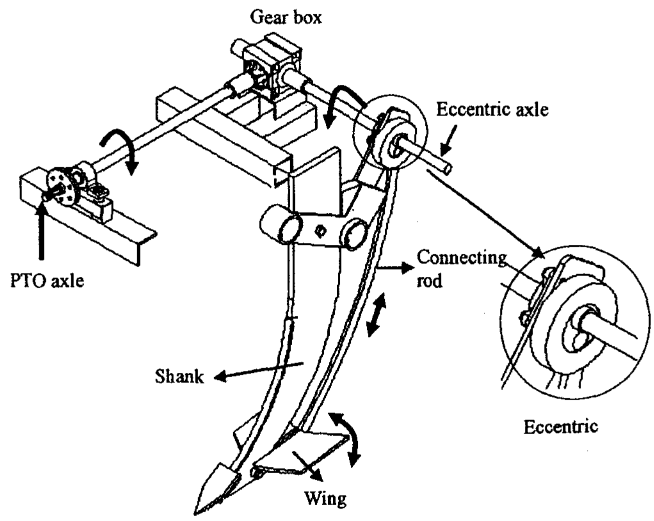


Figure 2 Eccentric crank mechanism to oscillate wing of vibratory subsoiler

On the third prototype, oscillation was accomplished through a crank and rocker mechanism, as illustrated in Figure 3. In this prototype, a connecting rod was placed in front of the subsoiler shank. Similar to the second prototype, one complete rotation of PTO axle was associated with one complete cycle of wing vibration. Only amplitude of 63 mm was provided, operated at frequency between 4.6 Hz and 7.5 Hz. The tests were carried out at a speed of between 1.2 km/h and 2.2 km/h.

All the prototypes were dual row subsoilers. In order to minimize imbalance of the constructions during oscillation, modes of shank vibration or wing vibration were designed to have 180 degree phase difference.

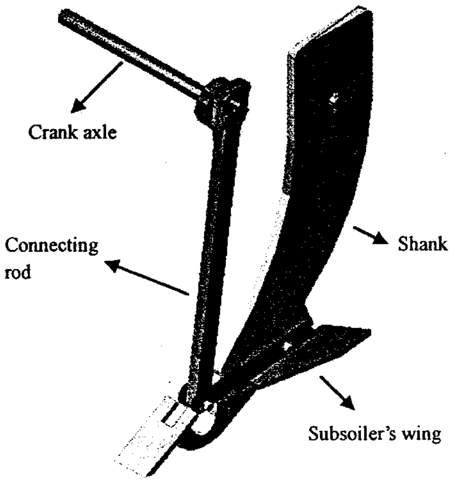


Figure 3 Crank mechanism to oscillate wing of vibratory subsoiler

2.3 Instrumentation and data measurement

During field tests, parameters measured were draft, rotation speed of PTO, traveling speed of tractor, tractor slip, and working depth subsoiling operation. Draft was measured using a 5 ton load cell which was positioned between the pulling tractor and subsoiler driven tractor, as schematically illustrated in Figure 4.

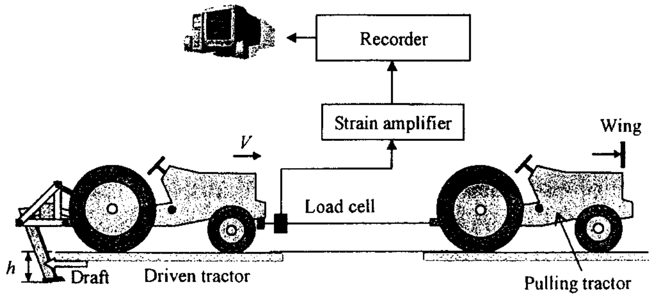


Figure 4 Draft measurement

The rotation speed of the PTO was measured manually using a digital tachometer. The traveling speed of the tractor was calculated by measuring travel distance and time for each set of five rotations of the traction wheel. Tractor slip was measured by measuring travel distance without load and travel distance with load at each 5 rotations of tractor's traction wheel. Working depths were sampled and measured manually using a stainless ruler stick.

3 Results and discussion

3.1 Shank oscillation

The prototype is shown in Figure 5. The prototype is a dual row tilted straight shank with cylindrical type subsoiler foot. All the tests were carried out using a 52 kW 2WD tractor (Deutz). The subsoiler shank was designed to have the ability to work at a depth of 50 cm. However, due to the limited power of the tractor, the subsoiler could not reach the desired depth.

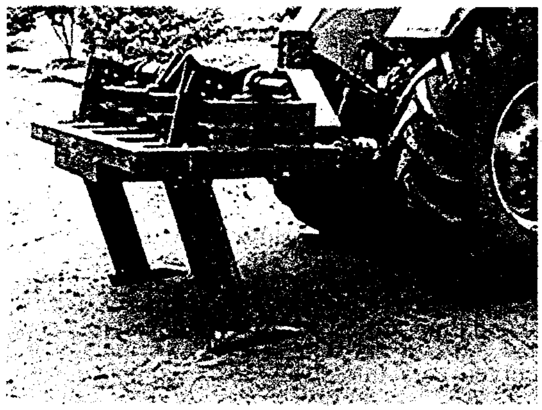


Figure 5 Prototype of shank oscillation on subsoiler (Radite, Wawan and Suastawa, 2003)

Generally, the draft of the subsoiler with oscillation mode was less than that without oscillation. As shown in Figure 6, draft on vibration mode tended to decrease with the increase of velocity ratio, as was also observed by other researchers (Al-jubouri, et al, 1984; Bandalan, et al, 1999), when velocity ratio was greater than 3. As velocity ratio[①] increased, the effect of increased

① In this paper velocity ratio is defined as "maximum velocity of vibration divided by forward speed".
Velocity of vibration = $2\pi fb$, where f = frequency of vibration, Hz; b = amplitude of vibration, m.

requency had a greater effect than that of increased amplitude of oscillation. As depicted in Figure 6, the reduction of draft on the shank vibration technique was in the range of 24.4% to 61.4%.

At operating speed between 1.8 and 2.2 km/h (average 1.9 km/h), the recorded drafts of the subsoiler in operation without oscillation ranged from 11.44 to 15.44 kN with an average of 13.38 kN. While at operating speed of 2.7-3.4 km/h (average 3.2 km/h), the drafts ranged between 16.43 and 20.04 kN with an average of 18.43 kN.

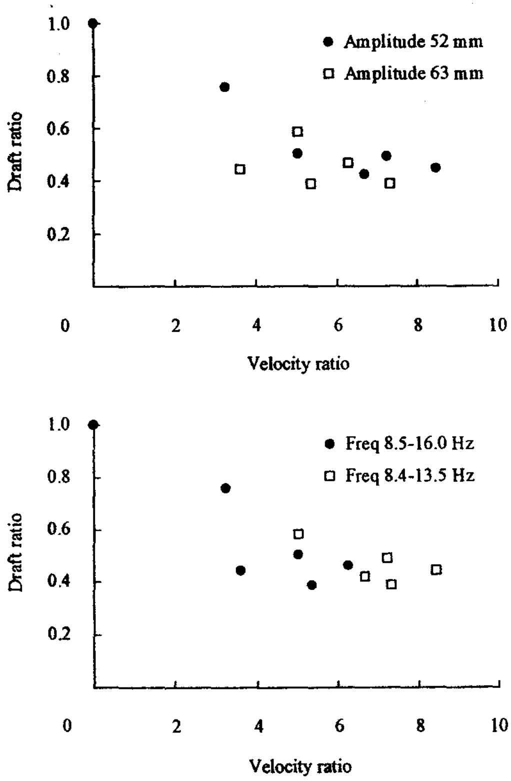


Figure 6 Effects of frequency and amplitude on draft ratio of subsoiler

On vibration mode with an amplitude of vibration of 52 mm, range of vibration frequency between 8.5 and 16.0 Hz, and range of forward speed between 2.0 and 4.3 km/h, the range of subsoiler draft was between 4.07 and 12.99 kN with an average of 7.94 kN. While on vibration mode with an amplitude of vibration of 63 mm, range of vibration frequency between 8.4 and 13.5 Hz and range of forward speed between 2.1 and 4.0 km/h, the range of subsoiler draft was between 4.1 and 10.9 kN with an average of 7.2 kN.

The two operation modes' average working depth was similar, about 32 cm. Working depth in operation without oscillation was in the range of 30.1-33.3 cm, with an average of 31.9 cm. Working depth of subsoiler operation in vibrating mode was in the range of 28.2-35.9 cm with an average of 32.2 cm

3.2 Wing vibration prototype I

The prototype is shown in Figure 7. In this design, the subsoiler shank remained fixed while oscillation was applied on the subsoiler wing. Therefore, the main movement of the wing is in upward and downward direction that greatly differed from the previous design, which promoted forward and backward motion of the shank, especially of the subsoiler foot. Wing oscillation is used in this design in order to minimize vibration transferred to the body of tractor. It was anticipated that upward-downward oscillation would not cause soil fracture as effectively as backward-forward oscillation. Therefore, in order to obtain more reduction of total draft, this design used a parabolic shank because it has less draft compared to tilt straight shank (Tupper, 1997).

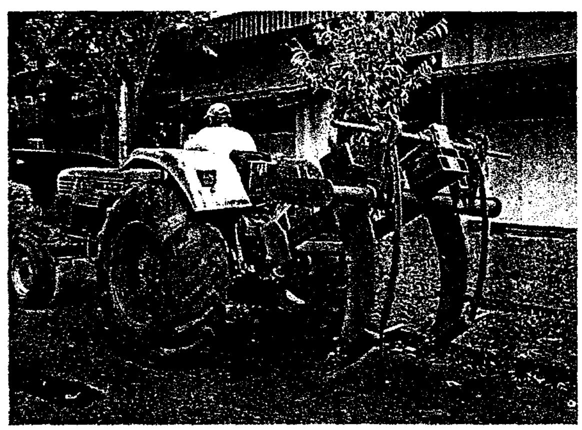


Figure 1 Vibratory wing subsoiler prototype I

During the field test, the prototype was pulled by a 52 kW 2WD tractor (Deutz). The test was conducted at a relatively constant working depth ranging between 38 and 41 cm, with an average depth of 39 cm. It was recorded that the draft of the subsoiler operation without oscillation was in the range of 8.97-10.26 kN with an average of 9.62 kN when operated at forward speed between 1.5 and 2.2 km/h.

All tests on subsoiler operation under oscillation mode resulted in drafts which were less than those without oscillation. When the subsoiler was operated under oscillation mode at amplitude of 73 mm, range of frequency between 7.3 and 12.2 Hz, and range of forward speed between 1.6 and 2.3 km/h, the draft of the subsoiler was in the range of 5.4-6.9 kN. At amplitude 64 mm, range of frequency of oscillation between 7.7 and 13.2 Hz, and range of forward speed between 1.7 and 2.3 km/h, the subsoiler draft was recorded in the range of 6.1 to 7.3 kN. Lowest average draft was 5.77 kN, reached when the subsoiler was operated at frequency of 11.5 Hz, amplitude of oscillation of 73 mm and forward speed 1.8 km/h. Maximum average draft was 6.95 kN, reached when the subsoiler was operated at 7.9 Hz, amplitude of oscillation of 73 mm and forward speed of 2.2 km/h. In general, tractor wheel slip on subsoiling operation under oscillation mode was less than that without oscillation. The ranges were from 6.5%-11.0% and 11.5%-15.3%, respectively.

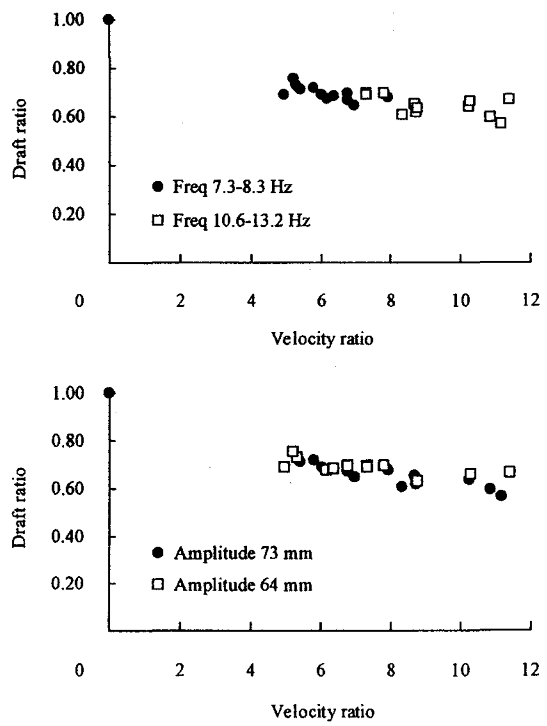


Figure 8 Effects of frequency and amplitude on draft ratio of vibratory wing subsoiler

As well as previous results, in the wing oscillation technique, the increase of velocity ratio also reduced draft ratio, as shown in Figure 8. It was shown that increasing amplitude or increasing frequency gave more draft reduction. However, increasing frequency gave more favorable results than those of increasing amplitude of oscillation. Increasing amplitude from 6.4 mm to 7.3 mm gave about a 14% increase in draft reduction, from range of 24.6%-36.9% to 28.2%-43.5%. Increasing frequency of vibration, from operation range of 7.3-8.3 Hz to 10.6-13.2 Hz, increased draft reduction about 23%, from a range of 24.6%-35.4% to a range of 30.3%-43.5%.

3.3 Wing vibration prototype II

The difference between wing oscillation techniques on prototype I and prototype II was the construction of the connecting rod that drives the subsoiler's wing. In prototype I, the connecting rod was placed behind the shank. In prototype II, the connecting rod was placed in front of the shank. Positioning the connecting rod in front of the shank was a difficult choice to make, because the subsoiler would be coupled with a granular fertilizer applicator. This design was questioned initally and raised much discussion among the design team. It was expected that the connecting rod would fail easily because it faced undisturbed soil before the shank. However, it was observed during field tests that the prototype could work well. The prototype under test is shown in Figure 9. As shown in the photo, the soil failure happened before the connecting rod passed the soil. It was understood that this occurred because of the subsoiler's feet or shoes.

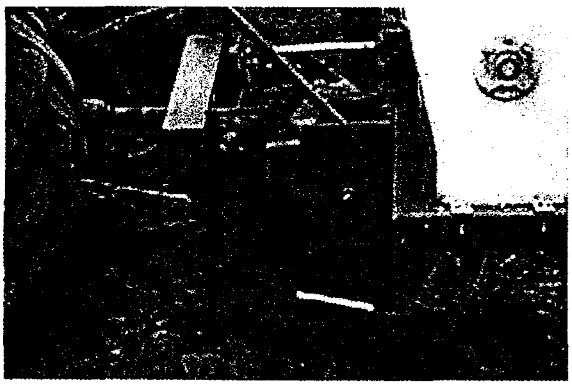


Figure 9 Vibratory wing subsoiler under field test at Bogor

When measurement was conducted, the condition of field was very dry. Average soil moisture content at the depth of up to 40 cm was 24.6%, which was far below the value of its plastic limit, which was about 51.2%. Therefore, the average draft of subsoiler without vibration was recorded in the ranges of 15.94-19.04 kN and 18.04-18.31 kN when it was operated at speed range of 1.0-1.1 km/h and 1.2-1.7 km/h, respectively. Wheel slip the tractor when operated without vibration was in the nge of 27.4%-39.0% with an average of about 32.8%.

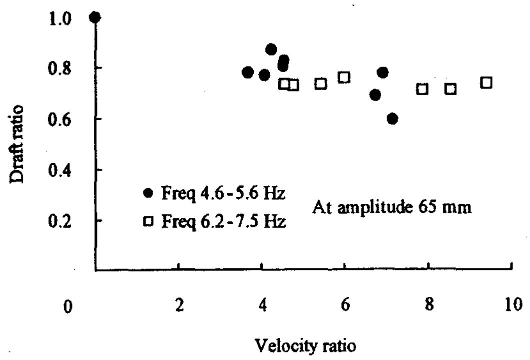


Figure10 Effect of velocity ratio on ratio of draft on subsoiler wing vibration prototype II

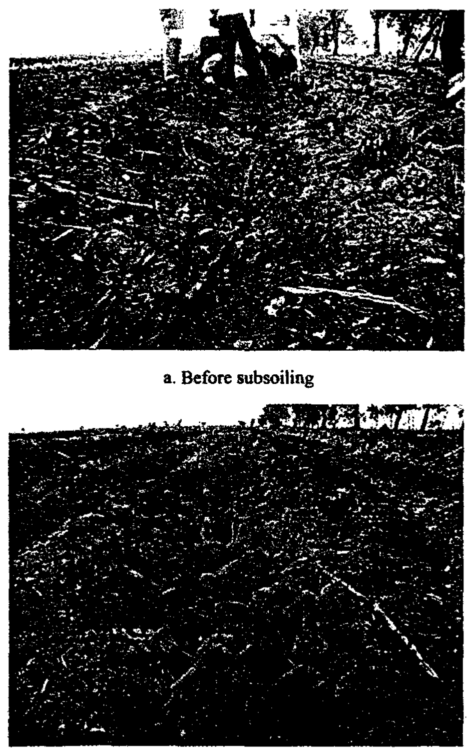
Tests of the subsoiler in oscillation mode were onducted at a single amplitude of oscillation of 65 mm, orward speed range of 1.1-2.4 km/h and frequency of scillation ranging between 4.6 and 7.5 Hz. It was bserved that higher frequency at the same forward speed ave less draft. As shown in Figure 10, draft ratio ecreases with the increase of velocity ratio but decreases o more at velocity ratio geater than 7.

At frequency range between 4.6 and 5.6 Hz and orward speed between 1.0 and 2.0 km/h, recorded drafts vere in the range of 10.36-15.13 kN. Compared to the peration of subsoiler without oscillation, draft could be educed about 13.3% to 40.7%, with an average of 4.9%. While at a similar range of forward speed 1.1-2.4 km/h) and higher frequency of vibration (6.2-'.5 Hz), the recorded drafts were in the range of 2.35-13.19 kN. Compared to the operation of the ubsoiler without oscillation, it reduced draft about 24.5% o 29.3% with an average of 27.2%. Wheel slip of the ractor when operated on oscillation mode was in the ange of 13.3-23.2% with average of about 17.2%, which vas 53% of wheel slip of the tractor without oscillation.

When testing at Leuwikopo field with a 52 kW 2WD ractor (Deutz), it was observed that working depth was in he range of 36-38 cm with an average of 37.0 cm. When the prototype was tested at the first ratoon field of the sugar cane plantation at Jatitujuh, working depth of the prototype was recorded in the range between 37 and 51 cm with average 41.9 cm. Figure 11 shows the prototype under test at Jatitujuh sugar cane plantation operated with 82 kW 4WD tractor (Massey Ferguson).

Figure 11 Vibratory wing subsoiler prototype II tested with 110 hp tractor at Jatitujuh sugar cane plantation

Operation of subsoiler in vibrating mode not only reduced draft, but also pulverized tilled soil better. Figure 12 shows the result of subsoiler operation which was passed in between stubble of sugar cane in the first ratoon field at Jatitujuh during dry season. It is shown in the figure that the soil could be plowed well and that operation of the subsoiler in vibrating mode resulted in more up lift of soil clod.



a. Before subsoiling

b. After subsoiling

Figure 12 Sugar cane ratoon field before subsoiling and after subsoiling

As shown in Figure 13, shank oscillation mode gave higher draft reduction than the prototypes of the wing vibration technique. As observed during field tests, the wing vibration technique had more of an advantage than the shank oscillation technique in sense that vibration transferred to the tractor body was greatly reduced. The shank oscillation technique gave draft reduction of 24.4%-61.4%. The wing oscillation technique on prototype I operated at a velocity ratio range between 4.9 and 11.4, and gave draft reductions in the range between 24.6% and 43.5%. The oscillation technique on prototype I operated at a velocity ratio range of 3.7-9.4, and gave draft reductions in the range between 13.3% and 40.7%.

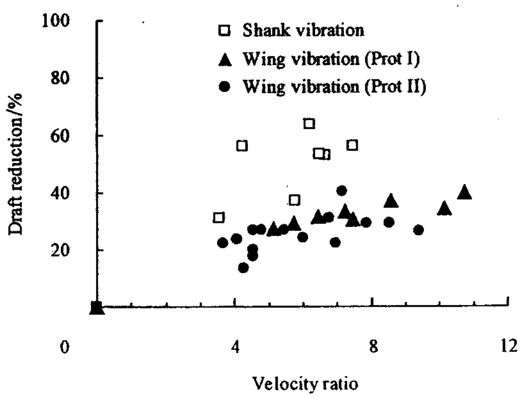


Figure13 Draft reduction on various technique of vibration

4 Conclusions

The experimental results from several tests showed that introducing vibration on soil tillage tools could reduce draft of soil working implements. On subsoiler operation, shank oscillation or the method of direct oscillation on subsoiler shank gave more effective results on draft reduction; however, visual observation showed that the tractor had also experienced rude vibration during operation. Use of the shank oscillation technique on vibratory subsoiler reduced draft up to 60%.

Use of the wing vibration technique on vibratory subsoiler also decreased draft, but the value of draft reduction was less than that of shank oscillation. The wing vibration technique could only reduce draft up to 40%; however, it significantly reduced the transmission of vibration through the body of the tractor.

Mechanisms to oscillate subsoiler wings need a connecting rod which can be positioned behind the shank or in front of the shank. The prototype that put the connecting rod behind the shank gave 10% greater draft reduction than the prototype with the connecting rod in front of the shank. However, positioning the connecting rod in front of the shank had advantage of simplicity in design and construction of the vibratory mechanism.

Acknowledgements

The authors gratefully acknowledge the support of the Directorate of Research and Community Services, Directorate General of Higher Education, Ministry of National Education of Indonesia, and Rajawali Nusantara Indonesia Corp., which provided a research grant for this work.

[References]

[1] Al-Jubouri, K. A., and P. B. McNulty. 1984. Potato digging using orbital vibration. *Journal of Agricultural Engineering Research* 29: 73-82.

[2] Bandalan, E. P., V. M. Salokhe, C. P. Gupta, and T. Niyamapa. 1999. Performance of an oscillating subsoiler in breaking a hardpan. *Journal of Terramechanics* 36 (2): 117-125.

[3] Butson, M. J., and D. MacIntyre. 1981. Vibratory soil cutting. I. Soil tank studies of draught and power requirements. *Journal of Agricultural Engineering Research* 26(5): 409-418.

[4] Dubrovskii, A. A. 1956. Influence on the draft resistance of oscillating tillage tools. Sbor. Trud. zemled. Mekhan vsesoyoz. Lenin. Akad. selkhoz. Nauk, 3: 182-185 (Natl. Inst. Agr. Engin., Eng. Translation 51).

[5] Gunn, J. T., and V. N. Tramontini. 1955. Oscillating of tillage implement. *Agricultural Engineering* 30(11): 725-729.

[6] Niyamapa, T., and V. M. Salokhe. 2000. Soil disturbance and force mechanics of vibrating tillage tool. *Journal of Terramechanics*, 37(3): 151-166.

[7] Radite, P. A. S., H. Wawan, and I. N. Suastawa. 2003. Development of 2-row vibratory subsoiler (*in Indonesian language*). *Jurnal Ilmiah Pertanian Gakuryoku* 9(2): 181-186.

[8] Tupper, G. R. 1997. Low till parabolic subsoiler: a new design for reduce soil surface disturbance and power requirement. Bulletin 858. Miss. Agric. and Forestry Exp. Sta. Miss. State Mississippi. 3p.

[9] Taylor, R., M. Schrock, and K. Wertz. 1991. Getting the most from your tractor. Department of Agricultural Engineering. Cooperative Extension Service, Kansas State Univeristy, Manhattan.