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Performance of combined tillage tool operating under four different linkage configurations

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ABSTRACT

Since tillage is one of the processes requiring high power, energy consumption in field operations is of great concern to farmers and researchers. A combined tillage tool has been recognized as one measure to reduce the power requirements in field preparation. In this research work, a combined tillage tool consisting of a subsoiler and rotary harrow (joined using four different linkage configurations) were tested under actual field conditions. The test parameters consisted of: tillage tools (combined tillage tool with four different linkages, a sole subsoiler and a sole rotary harrow), forward speeds (1.79, 2.67, and 3.33 km h^{-1}), and rotational speeds of the rotor (299 and 526 rpm). The experiment site was located at 14.00 °S and 99.58 °E having a clay soil type and bulk density in the range 1.5–1.7 g cm^{-3} with an average water content of 16.6% (db). The results indicated that the combined tillage tool was able to reduce the draft for subsoiling by 4.4–11.3% depending on the linkage configuration compared with the same sole subsoiler used alone. There were significant effects of the rotational speed of the rotary harrow and the forward speed on the drawbar power, the PTO power, and the total power. The combined tillage tool with linkage IV consumed the least total power. The combined tillage tool with linkages I to IV used less total power by 13.7, 12.2, 10.5, and 15.3%, respectively, compared with the combined power required by the sole subsoiler and sole rotary harrow working separately.

1. Introduction

Modernization of tillage tools plays an important role in agriculture now that farming has become a business rather than a way of life. Now more than ever, efficient management is the major key to success in the farming business (Bukhari et al., 1981). The high cost of energy today forces farmers to find alternative economic tillage methods (Bayhan et al., 2006). Therefore, the development of tillage tools capable of performing both primary and secondary tillage in one pass would be highly beneficial as this would reduce the cost of seedbed preparation (Kumar and Manian, 1986). Energy saving can be readily done by selecting energy-efficient implements and by the proper matching of tractor size and operating parameters to the implements (Ranjbarian et al., 2017). This not only helps to reduce the energy consumption of implements but also increases tillage performance (Weise, 1993).

In Thailand, soil compaction is a very severe problem mainly caused by agricultural machinery. A consequence of heavy equipment is the risk of soil compaction (Hadas, 1994; Jones et al., 2003) as the number of wheel passages of a tractor has harmful effects on both crop growth and yield (Usaborisut and Niyamapa, 2010; Alakukku and Elonen, 1995). One of the most effective ways to reduce the number of field trips and thus reduce field operations is to use combined machinery (Dhakane et al., 2010; Akbarnia et al., 2010; Sahu and Raheman, 2006).

A rotary tiller is a popular form of combined tillage tools, taking advantage of the forward thrust to help reduce draft. However, the forward thrust can be harmful to the drive train of the tractor (Wismer et al., 1968). An active tillage machine such as a rotary tiller contributes power in return to the tractor's drawbar by pushing the tractor (Prem et al., 2016; Shinners et al., 1993). Taking advantage of the negative draft of the active implement supplies a portion of the draft requirements of the passive machine in a combined tillage tool (Ahmadi, 2017). The combination of active and passive machinery can create lower resistance than from the passive machine alone (Manian et al., 1999; Weise, 1993). Moreover, it also possible to save 44–55% of costs and 50–55% of time by using a combination tillage tool for seedbed preparation (Kailappan et al., 2001). Combination tillage machinery was able to reduce the draft and fuel consumption (Shinners et al., 1990). In addition, wheel slip was reduced by at least 55% with combined machinery (Shinners et al., 1993).

Draft and power requirements are key parameters for measuring the performance of a tillage tool and therefore are considered as essential data when attempting to correctly match tillage to tractor (Al-Janobi

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and Al-Suhaibani, 1998). One of the main indices of energy consumption in tillage operation is the overall energy efficiency of the tractor. (Ranjbarian et al., 2017).

Since there are few data available on a combined tillage tool using a subsoiler and a rotary harrow, this study tried to clarify the working performance of this kind of combined tillage tool. This combined tillage tool may use the ability of the rotary harrow in creating force to help improve the performance of the subsoiler and the combined tool. With the assumption that the ways of joining two implements affect the working performance of the combined unit, the different linkage configurations between a subsoiler and a rotary harrow may be beneficial. Therefore, this study aimed to investigate the performance of the combined tillage tool (a subsoiler and a rotary harrow) with different linkage configurations compared with a sole, similarly configured subsoiler and a sole rotary harrow at different forward speeds and rotational speeds of the rotary harrow under actual field conditions.

2. Materials and methods

2.1. Description of the test site

This research was carried out in Kamphaeng Saen sub-district (14.00 °S and 99.58 °E), Kamphaeng Saen district, Nakhon Pathom province, Thailand. The soil type at the experimental site was clay identified using the hydrometer method described by Klute (1886). Determination of the consistency limits followed the procedures outlined in the USDA standards (USDA-NRCS, 2000). Soil samples were taken from two depths before the start of the experiment to determine the average bulk density and the average water content of the soil. Cone index values were taken at 0–50 cm depth using a hand-operated cone penetrometer with a conical tip with a 30° angle of penetration following procedures outlined in the ASAE Standards (ASAE S313.3, 2005). Soil properties are shown in Table 1.

2.2. Test implementation and instrumentation

A set of combined tillage tools was designed and developed to perform primary and secondary tillage operations in one pass for seedbed preparation. The combined tillage tool consisted of a subsoiler and a rotary harrow with a set of linkages as shown in Fig. 1. The subsoiler had two straight shanks with a lateral distance of 50 cm, attached to the rotary harrow having four rotors 25 cm apart and a total working width of 100 cm. With this configuration, each shank of the subsoiler was located between a pair of rotary harrow rotors. The combine tillage tool was powered by a Massey-Ferguson series 390 4WD 87 hp diesel tractor. The experiments were conducted to measure the performance of the tillage tool under different levels of three operating parameters: three forward speeds (1.79, 2.67, and 3.33 km h^{-1}); two rotational speeds of the rotor (299 and 526 rpm), and five tillage operations consisting of four one-pass tillage operations by the combined tillage tool with four types of linkage configurations between the subsoiler and the rotary harrow (linkage type I, linkage type II, linkage type III and linkage type IV as shown in Fig. 2) and a two-pass tillage operation using a sole subsoiler followed by a sole rotary harrow. The designs of the four linkage configurations were: "linkage I" allowed the force of the rotary harrow acting directly to the frame of subsoiler and the shank fixed with the frame; "linkage II" allowed the shank of the subsoiler to pivot when the force of the rotary harrow was pushing the shank at below the pivot point through a parallel mechanism; "linkage III" allowed the shank of the subsoiler to pivot when the force of the rotary harrow was pushing the shank at below the pivot point; and "linkage IV" allowed the shank of the subsoiler to pivot when the force of the rotary harrow was acting on the shank at above the pivot point.

The instrumentation system was set to measure the force, PTO torque and rotational speed, and the actual forward speed. The drafts of the combined tillage tool were determined using six pin transducers at the three-point hitch of the tractor and the three-point hitch between the subsoiler and the rotary harrow. The draft was sensed by the bending of the pin, using a technique involving mounting two gauges (Kyowa, KFG-5-120-C1-11L1M2R) in tension and two gauges in compression at each pin with the full-bridge circuit as shown in Fig. 3. The first set of pin transducers used for determining the total draft of the combined tillage tool (two pin transducers for the lower hitches and one pin transducer for the top hitch) and the second set of pin transducers used for measuring the draft of the rotary harrow. Two sets of pin transduces helped specify the draft of individual implements for the whole combined tillage tool. The PTO torque and speed were measured using a torque transducer (TP-50KMCB, Kyowa Electronic Instruments Co. Ltd., Tokyo, Japan) and an inductive sensor. A universal recorder (EDX-200 A, Kyowa Electronic Instruments Co. Ltd., Tokyo, Japan) was used to amplify and record all signals. Data were taken at a sampling rate of 200 Hz.

2.3. Test methods

The operating depths of the combined tillage tool during the test were controlled by the position control system of the tractor and set at 40 cm for the subsoiler and 20 cm for the rotary harrow. Experimental blocks 30 m long x 1.5 m wide were used for treatments. Tillage efficiency parameters were measured using three replications. The experiments for the units working separately as a sole subsoiler and a sole rotary harrow were also conducted and compared with the performance of the combined tillage tool. In total, 90 tests were conducted: 72 tests for the combined tillage tool and 18 tests for sole implements.

The data were analyzed statistically using a factorial design. Analyses of variance were made on performance parameters (draft, drawbar power, PTO power, and total power). Duncan's multiple range tests were used to determine significance at a probability level of 5%.

Table 1
Soil classification, water content of soil, and cone index of the experimental field.

Soil composition*	($g\ kg^{-1}$)	
Sand	211	
Silt	356	
Clay	432	
Consistency limits classification	Clay**	
Plastic limit (% by mass)	21.7	
Liquid limit (% by mass)	34.5	
Soil cone index (MPa) at depth of	Range	Average
5–20 cm	3.2–5.0	3.8 ± 0.9
20–50 cm	1.8–3.2	2.2 ± 0.7
Dry bulk density ($g\ cm^{-3}$) at depth of		
5–15 cm	1.5–1.7	1.6 ± 0.1
20–40 cm	1.6–1.7	1.7 ± 0.1
Water content of soil (% db) at depth of		
5-15 cm	11.0–17.3	14.3 ± 3.2
20-40 cm	17.8–21.1	19.0 ± 1.7

* Hydrometer test (Klute, 1886).

** Following the procedures outlined in the USDA standards (USDA-NRCS, 2000).

3. Results and discussion

The results of measuring the draft for each implement and of the combined tillage tool in the field tests are shown in Table 2. The draft of the subsoiler in the combined tillage tool with all linkages was in the range 25.5–33.8 kN. On the other hand, the draft requirement of the sole subsoiler ranged from 27.2 to 36.0 kN. The average draft for the subsoiler of the combined tillage tool with linkages I to IV could be reduced by 4.4–11.3% compared with the subsoiler working alone. The previous work indicated that the horizontal axis rotor can help to reduce draft requirement of the passive chisel tines in the combined