System Instrumentation and Modeling of Power and Energy Requirements for Tillage Operations in Malaysia

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Introduction

Management decisions related to agricultural machinery affect plantation profit in many ways. To improve productivity, it is necessary to have detailed information on the energy input of the utilized machinery in the area of locality. Most agricultural machinery management data are made available in ASAE Standard D497.3 (ASAE, 1997a). However, only limited data defining power and energy requirements of agricultural implement on various field operations and types of soil are presented in the standard.

The Department of Biological and Agricultural Engineering, Universiti Putra Malaysia had made an initiation to design and develop a data acquisition system and incorporate together the already built-in tractor instrumentation to provide comprehensive information on tractor and implement field performance within the framework of integrated system for an agriculture database. The already built-in instrumentation on board the tractor is able to measure and display information on engine speed, PTO speed, forward speed, drive wheel slippage, acres worked, fuel consumption per hectare, acres per hour, cost factor, fuel consumed, fuel remaining, and distance travel. The data acquisition that had been developed consists of a locally designed and fabricated drawbar pull transducer to measure horizontal pull at tractor drawbar, wheel torque transducers to measure torque at tractor drive wheels, PTO shaft torque transducer to measure the torque at factor PTO output, and a 3 point auto hitch dynamometer to measure the horizontal and vertical forces on the tractor linkages. Extensive field-testing would to be carried out with instrumented tractor on the aspects of power demand and energy requirements for various agricultural field operations in Malaysia. This Information is very important for selection of machinery, matching of implement to tractor and estimating fuel consumption. This paper presents the development of draft and fuel consumption models for four major tillage implement used in Malaysia and the comparison with published literature as well as summary of power and energy requirements of these implement.

Materials and Methods

A 64 kW Massey Ferguson 3060 (PTO power 51 kW, OECD test No. 6102) was used to collect data on tractor and implement performance during the tillage experiments. The tractor equipped with on board instrumentation system consisted of factory installed Datatronic instrumentation system and additional developed data acquisition system (Kheiralla and Azmi Yahya, 2001). Tillage experiments were carried out with four tillage implement comprising of 2-900 RANSOMES TS general purpose moldboard plow, 3-660 NARDI BTDN500 disk plow, 7-550 RANSOMES HR36 tandem disk harrow and 36-1550 HAWARD HR39 rotary tiller on three 1.05 ha plots at the University's farm for 1999 and 2000 year. These implement are representative of the tillage implements most commonly used for seedbed preparations of major cash crops in Malaysia. Prior to initiate the actual tillage operations, the plots were slashed once by a tractor and rotary slather to remove the available cultivated undergrowth. A statistical design used for each implement was a 2x4x3 factorial design with two level of years, four level of travel speeds, three level of tillage depths and three replications. The travel speeds used for each tillage implements were 3, 4, 5 and 6 km/hour. These travel speeds were achieved by adjusting engine throttle at reduced engine speeds (1500 -1900 rpm) and at four different settings. The tillage depths for disk plow and moldboard plow were 12, 17.5 and 23 and for the disk harrow were 12, 15 and 18 cm. For rotary tiller case, the travel speeds used were 3.3, 4.2, 5.1 and 6.2 km/h. These target speeds were obtained by operating the tractor at PTO speed of 540 rpm and adjusting the gear position at four different settings. Rotor speeds of 140, 175 and 200 rpm were maintained at tillage depth of 10 cm. Both travel speed and tillage depth variables were selected in equal increments to facilitate their transformation into orthogonal domain. Disk plow and moldboard plow experiments were conducted in undisturbed soil while disk harrow and rotary tiller followed disk and mold board plowing. Four adjacent plots each of 200-150 long x 60 m were used to run the tests. Validation tests on the developed models were made based on the special tests conducted in the 2000 year on a special allocated plot.

Results and Discussion

Draft models (D in kN/m) for moldboard plowing, disk plowing and disk harrowing on Serdang sandy clay loam soil was formulated based on travel speed (s in km/h) and tillage depth (d in cm) using orthogonal regression procedure. Power model (P in kW/m) for rotary tilling was formulated based on travel speed (s in cm) and bite length (b in cm) using the same procedure. The formulated draft and power models were as follows:

$$D_M=0.5380+0.4559d-0.0107d^2-0.6054s+0.0905s^2+0.0712d\times s$$

$$D_P=4.5877+0.0687d-0.7630s+0.1722s^2+0.0407d\times s$$

$$D_H=-1.2723+0.1421d+0.9328s-0.0676s^2$$

$$P_R=-6.7903-1.2593B+0.0684B^2+9.9205s-0.3269B\times s$$

The implement draft could be successfully predicted with respective developed models with good accuracy. Predicted draft for moldboard plow and disk harrow were respectively 1.24 and 1.73% higher than the measured draft magnitudes while predicted draft for disk plow and rotary tiller were respectively 1.05 and 1.73% lower than the measured draft magnitudes. Drafts predicted by moldboard plow and disk harrow draft models on Serdang sandy clay loam soil were respectively 4% and 1% underestimated by ASAE Standards D497.3 (ASAE, 1997). However, the drafts were respectively 20% and 10% overestimated by ASAE D497.3 at the lower extreme; whereas, the drafts were 9% and 5% underestimated by ASAE Standard models at the other extreme. Furthermore, comparisons on the draft model for disk plow and power model for rotary tiller with the ASAE D497.3 could not be made simply because their models were not listed.

Fuel consumption models (Fc in L/h) for moldboard plowing, disk plowing, disk harrowing and rotary tilling on Serdang sandy clay loam soil were formulated based on drawbar or PTO power (kW) as well as equivalent PTO power (kW). The formulated fuel models were as follows:

$FC_M=0.3450P_{BD}+4.2090$

$FC_M=0.2507P_{EQ}+3.3264$

$FC_P=0.2131\ P_{BD}+4.5160$

$FC_P=0.2130P_{EQ}+3.7934$

$FC_H=0.2926P_{BD}+5.5275$

$FC_H=0.1942P_{EQ}+4.7118$

$FC_R=0.2156\ P_{PTO}+6.2347$

$FC_R=0.1882P_{EQ}+5.2422$

The implement fuel consumption could be successfully predicted with respective developed models with good accuracy Predicted fuel consumption for moldboard plow, disk plow, disk harrow and rotary tiller were respectively 0.74, 2.58, 1.76 and 3.4% higher than the measured fuel consumption magnitudes. Fuel consumption predicted by ASAE D497.3 were found to be 17% to 33% overestimated of the fuel consumption predicted by the developed fuel models. However, fuel consumption reported by OECD Tractor Test was found to be 94% to 109% of fuel consumption predicted by developed fuel models. Almost 37% to 52% of the measured fuel consumption for the various plowing operations were required to propel the tractor and the remaining percentage were meant for the actual task of working the soil. Furthermore, the use of plowing implement at high speed is more efficient and gives proper matching of implement to the tractor.

The mean fuel consumption of moldboard plow and disk plow were respectively 12% and 6% higher than that of rotary tiller. However, the fuel consumption of disk harrow was 37% lower than that of rotary tiller. Similarly, mean specific energy of moldboard plow and disk plow were respectively 50% and 44% higher than of rotary tiller. However, the specific energy of disk harrow was 37% lower than that of rotary tiller. Consequently, disk harrow was the most energy efficient implement in terms of fuel consumption and specific energy followed by rotary tiller, disk plow and moldboard.

Conclusions

A complete tractor instrumentation and data acquisition system was developed and installed in Massey Ferguson 3060, agricultural tractor for power and energy demand of the agricultural field operations in Malaysia. Four polynomial draft and power models from orthogonal regression analysis were formulated based on linear and quadratic of travel speed and tillage depth or bite length. Four linear fuel models from regression analysis were formulated based on drawbar power or PTO power as well as equivalent PTO power. Moldboard and disk harrow drafts predicted ASAE D497.3 underestimated 4% and 1% at lower extremes whereas were 9% and 5% overestimate at the higher extremes of the values predicted by the developed draft models. Fuel consumption predicted by ASAE D497.3 was 17% to 33% overestimated of the values predicted by the developed fuel models. Disk harrow was found to be the most energy efficient implement in terms of fuel consumption and specific energy followed by rotary tiller, disk plow and moldboard.

Benefits from the study

Establishment of the first available database on power and energy requirements for tillage operations in Malaysia. This database would enable farm managers to use computer modeling and simulation for a more analytical and systematic approach of managing their machinery. Consequently, the management of agricultural machinery could be made through knowledge of the tractor-implement performance factors rather knowledge from past experiences or trial and error basis.

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