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Research paper

Investigations on power requirement of active-passive combination tillage implement

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ABSTRACT

In the present study, laboratory experiments were carried out to measure the draft and torque requirements of combination tillage implement (cultivator in the front set and rotavator in the rear set) by varying soil cone indices, peripheral to forward speed ratios (u/v) and depth ratios for a cutting width of 0.41 m and 0.65 m under controlled conditions in a soil bin with sandy clay loam soil at an average moisture content of 10.5 ± 1.2% (dry basis). Individual implements (cultivator and rotavator) of cutting widths of 0.41 and 0.65 m were also operated under similar conditions. Using non linear regression analysis, equations were developed for predicting draft, torque and power requirement of combination tillage implement. The maximum absolute difference between observed and predicted values of power requirement of the implement was found to be 12.43%. Power requirement of the implement was 43.93 and 33.17% lesser than the combined power requirement of individual implements for cutting widths of 0.41 and 0.65 m, respectively. With increase in width of tillage implements, power requirement increases directly due to increase in volume of soil handled. However, with increase in u/v ratio, power requirement decreases due to lesser time the rotavator is in contact with soil. Hence, to reduce the total power requirement of an active passive combination tillage implement, it is better to operate at higher u/v ratio and lesser depth ratio.

1. Introduction

The energy use in field preparation is of great concern for scientists and farmers. Among all field operations, conventional tillage requires highest amount of energy input. It requires several passes of various soil-turning and soil-pulverizing equipments requiring more time, fuel and labour. Moreover several passes of tractor with tillage implement increase soil compaction (Classen, 1996). In order to overcome these difficulties, one has to reduce the number of passes required to prepare the seedbed without sacrificing the quality of work. This is possible by combining tillage implements to be operated simultaneously (Sahu and Raheman, 2006).

The combination tillage implement comprises combination of either active and passive or passive and passive tillage implements. In case of passive implements, power losses are more at tire-soil interface and also a considerable weight is required on drive wheels of tractor to provide necessary traction that results into detrimental soil compaction. Active tillage implements require considerable power per unit width as they till a greater volume of soil than is required in most field crop systems. Srivastava et al. (1993) stated that rotor develops a forward thrust resulting in a negative draft that may require further energy inputs to control tractor steering and three-point hitch and also may be harmful to the tractor drive train. A way to control this detrimental forward thrust is to combine active and passive elements that may result into following potential benefits:

i) Power for tilling the soil can be transmitted to the tillage elements through a mechanical power train more efficiently than through the tire-soil interface. Hendrick (1980) estimated an overall average power transmission efficiency of 82% for PTO powered active tillage elements and 49% for drawbar passive tillage elements.
ii) The negative draft of the active elements can be used to provide full or part of the draft of the passive elements and this will reduce draft of tillage tools and results in lesser wheel slip and

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improved field productivity and allow the use of lighter tractors to reduce soil compaction. Reduced draft of tillage tools will also allow operations to be performed in more difficult traction conditions requiring the use of extra ballast, dual tires or assistance from the front wheels (Shinners et al., 1990).

Chamen et al. (1979) developed and tested PTO driven rotary digger consisting of a rotary unit with L-shaped blades and deep chisel tines, mounted behind the rotary unit. They concluded that net energy requirement of rotary digger was 50% lesser than the conventional plough under similar operating conditions. Wilkes and Addai (1988) built and tested Wye double digger which consisted of a rotary subsoiler and an adjacent mould board bottom which turned next furrow onto the loosened subsoil. This digger reduced drawbar power, wheel slip and specific energy compared to mould board plough under similar operating conditions. Shinners et al. (1990, 1993) developed two combination tillage machines. The first machine had two active and two passive sets and the second machine consisted of an active rotary powered tillage set with conventional passive chisel tines. It was reported that combination machines required less draft and drawbar power than similar machines using purely passive tillage tools although total power consumption was same. The combination machines were more energy efficient than similar passive tillage tools. Weise (1993) performed experiments with combined arrangements of wing tines and a rotor with tines. He reported that pre-loosening of soil reduces the power requirement of following rotor. Manian et al. (1999) also reported that the energy, time and cost of operation for a combination tillage tool consisting of 16 tine rotary tiller and 2 to 4 chisel plow were reduced by 64.7–71.3%, 61.7–69.9% and 62.2–70.3%, respectively as compared to the combination of different implements when operated separately to obtain almost the same quality of tilth in black clay loam soil. A few more researchers (Kumar and Manian, 1986; and Kailappan et al., 2001a; 2001b) also combined active and passive units and reported saving in time and cost as compared to the conventional tillage practice. However, information on draft and torque requirements of combination tillage implements is very limited. The draft and torque requirement of tillage implement plays a vital role in developing more efficient tillage systems by matching the tractor with implement.

Keeping the above points in view, the present study was undertaken to measure draft and torque requirement of active-passive combination tillage implement at different soil, implement and operating parameters in the laboratory condition, to develop an equation for predicting the power requirement for the implement, to compare the power requirement of combination tillage implement with respective individual tillage implement and to identify the parameter responsible for minimizing the power requirement.

2. Materials and methods

2.1. Approach for prediction of power requirement of combination tillage implement

Based on theoretical approach on active-passive combination tillage implement proposed by Bernacki et al. (1972), a study on modelling power requirement of an active-passive combination tillage implement was carried out.

The specific work of a combination tillage implement consists of specific work of passive set and active set which can be expressed as

$$A_C = \lambda_P A_P + \lambda_A A_A \tag{1}$$

where, A_C is specific work of combination tillage implement (N/m^2), A_P and A_A are specific work of passive set and active set operating as individual implement, respectively (N/m^2). λ_P and λ_A are fractions of specific draft of passive and active implement acting as individual implement, respectively. These fractions values are always less than unity. A_C can also be written as summation of specific work of combination tillage implement resulting from pulling resistance, A_R (N/m^2) and specific work of combination tillage implement resulting from torque, A_T (N/m^2).

$$A_C = A_R + A_T \tag{2}$$

Draft of the combination tillage implement, D_C amounts to

$$D_C = D_P + D_X \tag{3}$$

where D_P is draft (N) of passive set and D_X is horizontal component of peripheral force (N) acting on the shaft of active set (Fig. 1).

In order to have a considerably lower draft of combination tillage implement than similar type of passive implements, active sets with concurrent revolutions are used in the combination tillage implement. Neglecting the specific work of active set A_C which results from the action of the component force D_X pushing the machine and comparing equations (1) and (2), the following equations could be obtain

$$\lambda_P A_P = A_R \tag{4}$$

$$\lambda_A A_A = A_T \tag{5}$$

Individual specific works are calculated according to the formulas

$$A_P = \frac{D_P}{a_P b_P} \tag{6}$$

$$A_R = \frac{D_C}{a_C b_C} \tag{7}$$

$$A_A = \frac{2\pi T_A}{a_A b_A l_g} \tag{8}$$

$$A_T = \frac{2\pi T_C}{a_C b_C l_g} \tag{9}$$

where *a, b* stand for depth and width of implement, respectively. *D, T* stand for draft (N) and torque (Nm), respectively. l_g is the travel length (m) covered by the machine at one full revolution of the shaft of the active set which is given as

$$l_g = \frac{2\pi V}{\omega} \tag{10}$$

where, V is forward velocity of implement (m/s) and ω is angular speed of rotavator shaft (rad/s).

By comparing equations (4) (6) and (7), coefficient λ_P could be calculated as

$$\lambda_P = \frac{A_R}{A_P} = \left(\frac{D_C}{a_C b_C}\right)\left(\frac{a_P b_P}{D_P}\right) \tag{11}$$

By comparing equations (5) (8) and (9), coefficient λ_A could be calculated as