Optimal Draft requirement for vibratory tillage equipment using Genetic Algorithm Technique

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Abstract. Agriculture is an important sector of Indian economy. Primary and secondary tillage operations are required for any land preparation process. Conventionally different tractor-drawn implements such as mouldboard plough, disc plough, subsoiler, cultivator and disc harrow, etc. are used for primary and secondary manipulations of soils. Among them, oscillatory tillage equipment is one such type which uses vibratory motion for tillage purpose. Several investigators have reported that the requirement for draft consumption in primary tillage implements is more as compared to oscillating one because they are always in contact with soil. Therefore in this paper, an attempt is made to find out the optimal parameters from the experimental data available in the literature to obtain minimum draft consumption through genetic algorithm technique.

1. Introduction

Mechanization plays an important role in Indian agriculture. Tillage is basically the mechanical manipulation of soil. There are two types of tillage mainly, Primary and Secondary tillage. Different kinds of implements such as mouldboard plough, disc plough and cultivator etc. are used for tillage operation purpose [1,2]. Application of vibration in tillage application is reported since 1955. Several investigators have reported several advantages over rigid tillage. Various studies have reported that 50-60% draft reduction is observed in vibratory tillage. However, these equipment has not been fully explored by scientists and engineers [3,4].

2. Tillage:

Tillage is a mechanical manipulation of the soil performed for obtaining suitable conditions for seed germination, establishment, and its growth. It results in a good physical condition of the soil known as soil tilth. Primary and secondary tillage manipulation are the two different types of operations required for cultivation of any crop. Initial tillage depth of 25-30 cm is obtained through primary tillage. For finer operations and better seedbed preparation, a tillage depth of 10-15 cm is obtained in secondary tillage after primary tillage. Mouldboard plough, Disc plough, Subsoiler, Cultivator, Disc harrow and other miscellaneous equipment are different types of primary and secondary tillage implements as shown in Fig. 1. Nowadays tillage machinery is one of the developing areas to meet the challenges of finding new and better ways of utilizing energy for tilling the soil. Oscillatory or vibratory tillage equipment is one such type of implement which uses vibrations for its tillage operation.
2.1 Vibratory Tillage:

Tillage tool oscillates in a particular mode of oscillation with certain amplitude and frequency along with the implement forward speed as shown in Fig. 2 [5]. These tools have linear arc motion concerning implement reference system, and the mode of oscillation may be longitudinal or transverse. The plane of oscillation may be horizontal, vertical or at some inclination in three-dimensional space.

Primary Tillage Equipments

Three bottom Mould Board Plough  Three bottom Disc Plough
Subsoiler

Secondary Tillage Implements

Nine tyne Cultivator  Disc Harrow

Figure. 1: Different types of primary and secondary tillage implements
(Source: www.icar.org.in)
Fig. 2: Vibratory Tillage Implements  
(Source: Clemens Vineyard Equipment Inc, USA)

2.2 Draft

Draft and power consumption plays an important role in agricultural machines. Draft is basically defined as the opposite force offered by soil particles to the cutting tool as shown in Figure 3.

Figure 3. Resultant draft force acting on implement by soil particles

3. Literature Review:

Vibratory tillage concept was introduced in 1955 however the advantages of the application of vibration in tillage operation has not been fully explored by scientists and engineers. It is reported in a study that the forced vibration in a tillage tool results in minimizing the draft consumption [3]. A study conducted series of experiment on the application of vibration in tillage operations resulted in 60% of draft reduction [4,6,8,9]. Draft and other performance parameters of a simple vibratory tillage tool are studied and that resulted that vibratory tool is a valid alternative to conventional tillage [5]. A study reported the effect of vibration on draft and power requirements considering different tool and soil variables [7]. The study behind the draft reduction in the soil for vibration tillage concluded that vibrating tool fractures the soil which in turn reduces the soil cohesiveness [11]. Thus from the following reviews, it can be concluded that in vibratory tillage equipment draft reduction takes place during the tillage operation.
4. Methodology:

The main objective of the study is an attempt to apply the optimization method to the experimental data of vibratory tillage available from the literature and to find out an optimal set of vibratory tool parameters which will be useful to reduce in a significant draft reduction of the vibratory tool. Vibratory share tillage system is defined by three basic parameters such as forward speed, frequency, and vibration amplitude. From the literature available [6] experimental data is analyzed for forward speed, vibrator amplitude, and frequency. The measured parameter is vibrated draft. Data is used to form a suitable linear regression model to obtain a relationship between the design parameters and objective function which is draft consumption in this case.

A linear single objective optimization problem is formulated to minimize the draft consumption with amplitude, frequency and forward speed of the tool as design variables. Then the formulated problem is optimized through a genetic algorithm and compared with experimental results to suggest the proper setting of design variables.

4.1. Design Variables

The draft in vibratory mode can be represented by three parameters as amplitude, forward speed, and frequency. The design vector is defined as:

\[
[X] = \begin{bmatrix} \text{amplitude} & \text{forward speed} & \text{frequency} \end{bmatrix} \quad (1)
\]

4.2. Objective function and constraints

In optimization process objective function plays an important role. A linear regression equation of vibrated draft obtained through experimental data from literature [6] as shown in Table.1 is formulated.

The objective function is obtained concerning design variables. Optimality criterion is identified from the experimental data and proposed here as follows for minimization,

Vibrated Draft
Minimize: \[ Z = 0.09289 - 0.0326*(\text{amplitude}) + 1.4733*(\text{forward speed}) + 0.00238*(\text{frequency}) \]

Subject to:
\[
\begin{align*}
1 & \leq \text{amplitude} \leq 8 \\
0.15 & \leq \text{speed} \leq 0.55 \\
7 & \leq \text{frequency} \leq 50
\end{align*}
\]

(2)

| Trial No | Amplitude [mm] | Forward Speed [m/s] | Frequency [Hz] | Vibrated Draft [kW] |
|----------|----------------|----------------------|----------------|---------------------|
| 1        | 4.0            | 0.299                | 24.2           | 0.162               |
| 2        | 8.0            | 0.302                | 22.9           | 0.068               |
| 3        | 4.0            | 0.132                | 24.4           | 0.045               |
| 4        | 4.0            | 0.201                | 25.8           | 0.577               |
| 5        | 4.0            | 0.348                | 25.8           | 0.447               |
| 6        | 1.7            | 0.248                | 42.1           | 0.287               |
5. Results and Discussion

Genetic algorithm (GA) is a class of probabilistic optimization algorithms inspired by biological evolution process. They use the concept of natural genetics and natural selection [10]. This technique generates an initial population randomly and evolves through three main operators such as selection, crossover, and mutation. A small description about the three main operators is given below:

5.1 Selection operator

The preference is given to the individuals allowing them to pass on their genes through next generation and the goodness of fit depends on the individual. Through objective function or judgment, the fitness can be determined.

5.2 Crossover operator

This operator is the main factor which distinguishes the Genetic Algorithm from other optimization techniques. A new set of best good individuals created by mating are put into next generation of the population, and a set of good individuals is likely to be created even better than these individuals.

5.3 Mutation operator

The main aim of the mutation operator is to maintain the diversity within the population and to prevent premature convergence.

The technique is applied to the available experimental data from the literature to find out the optimal solution for minimum draft consumption. In MATLAB optimization toolbox solver "GA-Genetic Algorithm" is used to solve the objective function with proper lower and upper bounds as given in the literature.

5.4 Vibrated Draft condition

The convergence graph for GA function is shown in Fig. 4. The GA function value for minimum draft consumption is found to be 0.0407. Optimum parameter values obtained for amplitude, forward speed and vibrator frequency is 8 mm, 0.2 m/s and 7.9 Hz as given in Table 2. The results obtained were compared with experimental data of literature and it is found that the GA results suggest an optimal parameter setting for minimum draft consumption.
The significance meaning of minimum draft consumption is, the reverse force offered by the soil particles is reduced which in turn reduces the power consumption of the tractor. Thus this results in less consumption of fuel and energy of the prime mower which is a tractor in this case. Therefore draft and power consumption are vitally important for agro applications which in turn will contribute towards the economic significance of the farming community and improve the efficiency of the system.

From the Table 2, it is observed that vibrator frequency has reduced from 24.4 Hz to 7.9 Hz. Thus this justifies that to provide a high frequency to the tillage tool more power consumption is required for the vibratory system which results in more energy consumption of the system. So, in this study, results obtained through optimization technique suggested to keep the vibrator frequency low for the same required output which is advantageous for energy saving.

| Parameters | Amplitude [mm] | Forward speed [m/s] | Vibrator frequency [Hz] | Draft [kW] |
|------------|----------------|---------------------|-------------------------|-----------|
| Experimental Value | 4.0          | 0.132               | 24.4                    | 0.045     |
| Optimized Value    | 8.0          | 0.200               | 7.9                     | 0.040     |
6. Conclusions

The minimization of draft consumption using a linear single objective optimization problem for vibratory tillage with proper amplitude, frequency, and forward speed is proposed in this study. The proposed parameters setting for minimum draft consumption will increase the efficiency of the machine performance which will improve the economic significance of the farming community. There is a reduction of 11% in draft consumption when compared with experimental data of literature. Thus optimization techniques help the farmers to select the proper parameters which can improve the efficiency of the tillage systems and can reduce unnecessary power losses.

Acknowledgments
Ph.D. scholarship granted by MHRD, Government of India to the first author is highly acknowledged.

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