A review on effect of vibration in tillage application

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Abstract. The paper deals with the application of vibration in tillage operations. Nowadays implements which can reduce draft and power consumption of tractor is the main area of concern to scientists and engineers. Vibratory tillage is one such concept in which there are many advantages over passive equipments. Thus a review based study has been made to identify the advantages that exist in active vibratory tillage equipment as compared to rigid tools.

Keywords. Tillage, Oscillatory tillage, Draft, Drawbar, Vibratory tool.

1. Introduction
Agriculture plays an important role in the developing economy such as India. Around 58% of the rural household population depends on agriculture as their principal occupation. Agriculture and its allied sectors contributes 14% to the nation Gross Domestic Product (GDP). India's food grain production has also marginally increased up to 252.23 million tonnes (MT) during 2015-16 [1,2]. Agriculture plays an important role to achieve an overall GDP target of 8 per cent during the 12th Five Year Plan (2012-17) and to meet the rising demand for food [3].

1.1 Agricultural Mechanization Status in India
Indian agriculture have brought technological improvements since mid sixties due to increased agricultural production. Farm power availability (Power available per unit area) has increase tremendously from 0.32 kW/hac (1965-66) to 2.02 kW/hac (2013-14) as shown in Table 1. Thus this justifies the strengthening of farm mechanization in the country for timeliness of operations [4]. The quality and precision of the different farm operations such as tillage, levelling, sowing and planting, plant protection, harvesting and threshing needs a higher degree of precision to increase the efficiency and to reduce farm loses. Thus, farm mechanization enables the farmers for the judicious use of farm power for agricultural production [5]. Adequate farm power plays an important role for timeliness of farm operations, increasing labour efficiency and reducing crop produce losses. The tractor density in India is about 27 tractors per 1,000 hectare as against the world average of 19 tractors per 1,000 hectare of cropped area. The increasing demand of timely operations made farmers to switch over to machine assisted farming from conventional farming [3,4].
Table 1: Cropping intensity and power availability on Indian farms [5]

| Year   | Cropping intensity (%) | Food grain productivity (t/ha) | Power available (kW/ha) | Power per unit production (kW/t) | Net sown area per tractor (ha) |
|--------|------------------------|-------------------------------|-------------------------|---------------------------------|-------------------------------|
| 1965-66 | 114.00                 | 0.636                         | 0.32                    | 0.50                            | 2162                          |
| 1975-76 | 120.30                 | 0.944                         | 0.48                    | 0.51                            | 487                           |
| 1985-86 | 126.80                 | 1.184                         | 0.73                    | 0.62                            | 174                           |
| 1995-96 | 130.80                 | 1.499                         | 1.05                    | 0.70                            | 82                            |
| 2005-06 | 135.90                 | 1.715                         | 1.49                    | 0.87                            | 45                            |
| 2010-11 | 140.50                 | 1.930                         | 1.78                    | 0.92                            | 34                            |
| 2011-12 | 141.50                 | 2.079                         | 1.87                    | 0.90                            | 31                            |
| 2012-13 | 140.90                 | 2.129                         | 1.94                    | 0.91                            | 29                            |
| 2013-14 | 142.00                 | 2.111                         | 2.02                    | 0.96                            | 27                            |

1.2 Tractorization in India

The Indian tractor industry is the largest in the world and accounts for one third of global population of tractors. There has been an increase in sale of tractors from 2,47,351 in 2004-05 to 5,71,249 in 2015-16 [6]. It was found that there has been increasing trend of tractor sales in different range of horsepower through the country. Uttar Pradesh accounts for (15.1%) tractor share followed by Madhya Pradesh (13.85%), Rajasthan (11.82%), Maharashtra (10.32%) and Gujarat (7.36%) as shown in Figure 1. Thus the extent use of mechanical power serves as an indicator of acceptance of higher level of technology in farms and the shift towards more use of mechanical and electrical power sources [7,8].

![Tractor Share](image1)

Figure 1. Tractor share of different States [6]
1.3 Tillage

Tillage is basically a mechanical manipulation of the soil performed for obtaining suitable conditions for seed germination, establishment and its growth. It results in 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 kind of crop. Primary tillage is carried out with an initial depth of 25-30 cm. Mouldboard plough, Disc plough and Subsoiler are the types of implements under primary tillage. For finer operations and better seedbed preparation of the soil secondary operations are carried out once the primary operations are completed. Tillage operation depth of 10-15 cm is obtained during this operation. Cultivator, Disc harrow and other miscellaneous equipments are the types of secondary tillage equipments used for tillage purpose. Soil Dynamics of Tillage is developing to meet the challenges of finding new and better ways of utilizing energy for tilling the soil. Oscillatory tillage equipment is one such type of implement which uses vibrations for its tillage operation as shown in Figure 2. The purpose of this paper is to examine the results of studies made for oscillatory tillage tool in soil engaging operations.

![Figure 2(a): Primary and Secondary Equipments](image)

![Figure 2(b): Oscillatory Equipment](image)

2. Oscillatory tillage

Primary and secondary tillage equipments are commonly used. However, the advantages of oscillating tillage equipment has not been fully explored by scientists and engineers. Oscillation of tillage implement was introduced in 1955 [9]. The tillage tools oscillate in a particular mode of oscillation with certain amplitude and frequency along with the implement forward motion. These tools have the linear or arc motion with respect to implement reference system and the mode of oscillation may be longitudinal or transverse. Plane of oscillation may be horizontal, vertical or at some inclination in three dimensional space.

Oscillating mode tools have several advantages over non oscillating one. Oscillating tools requires less draft as compared to non oscillating one. Various studies have reported that 50-60% draft reduction is observed while using oscillatory tillage equipment [9,11,13,14,17,18,19,44]. Soil compaction is reduced due to decreased traction requirement [10,19,26,32,33]. Soil crumbling is found to be observed good by using this tool [10,11,12]. There is a conflict regarding the total power
requirement of the tillage tool. It may increase, decrease or remain same for the tillage operation. Some researchers reported that there is an increase of 30-35% power consumption while using oscillatory tool [9,10,11,12,13]. The reason behind draft reduction in dry soils is because vibration tool fractures the soil which reduces the soil cohesiveness. For wet soils, stress pulses are transmitted through the soil resulting in burst of hydrodynamic pressure and excess pore water pressure which reduces the effective stress and soil strength [44].

Therefore, oscillatory tillage tool can mitigate the problems related to tillage applications. Thus a review based study has been carried out to identify the advantages and problems related to oscillatory tillage equipment.

3. Literature Survey
The main criteria for selecting the research papers for review purpose were on the following basis:

3.1 Draft force and power consumption.
3.2 Effect of vibratory tillage on the soil properties.
3.3 Design and development of oscillatory tillage equipment.
3.4 Effect of tillage tool parameters on performance.
3.5 Mathematical modelling of tillage tools.

3.1 Draft force and power consumption
Soil pulverization is a process of tillage that can be defined as a loosening of the soil [13]. It is well established that forced vibration in a tillage tool results in minimizing the draft consumption. Draft is defined as the opposite force offered by soil particles to the cutting edge of the tool, as shown in Figure 3. However, there is a conflict regarding total power requirement [9]. A study reported the effect of vibration on draft and power requirements considering different tool and soil variables [10]. An analysis of the relationship among draft, torque and power requirements of a simple vibratory tillage tool is studied and found that vibratory tool is a valid alternative to conventional tillage [13]. Study on oscillations imparting to the tillage tool has concluded that there is a linear dependence of draught force on the tillage tool and actual speed suggested [14]. Further a series of different experiments on soil tank has also concluded that draft of the tillage tool is reduced while applying sinusoidal vibration to the tool [15]. In vibratory tillage implement draft force is reduced by 35% as compared to rigid tillage [16,42]. A four shank vibrating subsoiler resulted in 60% of draft reduction in performance trials [17]. Several experiments confirmed that draft consumption decreased, but power requirement increased for oscillating mode tools. [18]. Studies on application of vibration on subsoiler resulted in draft reduction upto 60%. [19]. A series of field trials conducted in a sandy loam observed that draft consumption got reduced in oscillatory mode as compared to rigid tillage [20]. Tillage machine that combines active with conventional passive tools is tested and studied. It is observed that power transmission efficiency improves, draft reduction occurs and wheel slippage reduces. This concludes that cutting tools in motion increased efficiency [37]. Experimental tests confirms that vibrating tools ensure reduction in draft resistance which results in reduction of energy needed for tillage work [38]. A potato digging machine using orbital vibration was analyzed. It is
observed during the performance test that draft of the tillage equipment was reduced but power consumption increased during the tillage operation.

3.2 Effect of vibratory tillage on the soil properties

Different studies on clod size reduction evaluated that oscillation of a tillage tool influences clod size distribution [11]. A study on soil failure and soil disturbance under the action of vibratory tillage tools reported that soil fragment decreased in vibratory mode [21]. An Oscillator ripper is studied and results showed that reduction in traction resistance and bulk density is found for oscillating subsoiler as compared to non oscillating one [22]. A three treatment experiment such as rotary tillage, vibrating and nonvibrating subsoiling also concluded that bulk density and penetration resistance of the soil is reduced while using vibrating subsoiler which resulted in improvement of the soil properties [23]. A series of experiments in sandy loam soil resulted that traction resistance reduces while using vibratory mode tool [24].

3.3 Design and development of oscillatory tillage equipment

A study on design and development of vibratory tillage tool for power tiller operated included the modification in transmission system of power tiller and to design a new rotary shaft to impart oscillations and amplitude to the tool. To provide oscillation to the tillage tool, crank follower mechanism is provided and tested in terraced field conditions. Results concluded that soil handling in vibrating mode is better than non vibrating mode [25]. A two deep working oscillating tool for compacted vineyards is designed and developed. Oscillations are provided through crank rocker mechanism to oscillatory tool. Field experiments conducted in sandy loam soil resulted that power developed in oscillating tool is better than rigid tool [26]. A two tine oscillatory subsoiler is designed, developed and modelled for fracturing the compacted soil layers of grapevine farms. Oscillating tines were oscillated through crankshaft coupled to power take off shaft of tractor. Study concluded that there is a good correlation between theoretical and practical results obtained. [27]. Study on conservative tillage systems resulted in developing an alternative ground driven rotary multiple blades subsoiler. Field trials concluded that energy requirements were minimized by the developed tool [28]. A bionic vibrating subsoiler using functions of living organism or part of that is designed and developed for banana fields. Crank rocker mechanism converted the rotating power of gear box to reciprocating power of rocker. Results observed that draft force and fuel consumption is reduced significantly as compared to non vibrating mode [29]. For peanut crop a vibratory digger is designed, developed and tested on farm. Blade was vibrated through gearbox and cam assembly powered by
power take off shaft of tractor [36]. Study on performance of small commercial vibrating potato digger is performed and minimum design criteria for vibrating digger is proposed [41]. Similar vibratory digger blade for harvesting sweet potatoes is designed and developed. Effect of peak acceleration of vibration and combined effect of three variables namely (forward velocity, amplitude and frequency of vibration) on clod size and bulk density is analyzed in this experiment. It is observed that vibratory digger as compared to non vibrating one produced smaller soil clods and greater reduction in bulk density [38]. Study on mechanism design was carried out for paddy transplantation. A planar four bar mechanism linkage with coupler extension is selected and desired required output motion was obtained [39]. Similar theoretical design method is proposed by researcher for transplanting rice seedling. The method designs a non circular gears of a planetary gear train system to trace a prescribed trajectory [40].

3.4 Effect of tillage tool parameters on performance
Study on oscillatory ripper to find the optimum settings at different oscillating angles analyzed the optimum settings for better performance [26]. A series of experiments conducted in a soil bin with different tool parameters resulted that soil fragmentation is better in oscillatory mode than non oscillating one [12]. A simple tool system designed and developed also concluded that performance of an resonant subsoiler depends upon the tillage tool parameters [30]. Analysis on developed single shank tractor oscillating subsoiler reported that parameters of the subsoiler affects the performance of the tillage tool in sugarcane farms [31].

3.5 Mathematical modelling of tillage tools
A mathematical model developed reported that design parameters affects the performance of vibrating tillage tool and it is confirmed through field trials [32]. A model formulated to study the dynamic behaviour of fruit and stem concluded different predictions for fruit separation process[33]. Studies on sinusoidal vibratory tillage tool resulted in measuring average force accurately [34]. A three dimensional model of a oscillating subsoiler using discrete element method is developed and evaluated parameters that affects the simulation results are also identified [35].

4. Conclusion
The following study concluded that vibratory tillage tool enables the successful application of vibrations in soil manipulation process. The performance of the tillage tool is affected by vibrating tool parameters. It is reported that the draft requirement for vibrating tillage tool is less as compared to rigid tillage. Power requirement is still an issue, it may either increase, decrease or remain same depending upon the soil type and its properties. Soil fragmentation, traction resistance and bulk density of the soil is improved with vibratory tillage. Moisture retention capacity of the soil increases while using vibrating tool. Thus there is a huge potential and scope for vibratory tillage equipments in Indian agriculture which can improve the performance of the tillage operations.

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6. References

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