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# An experimental investigation of cultivator shank shape on draft requirement

**U. R. Badegaonkar*[1], G. Dixit[2] and K. K. Pathak[3]**

[1]*Central Institute of Agricultural Engineering, Bhopal, India*
[2]*Department of Applied Mechanics, MANIT, Bhopal, India*
[3]*Advanced Material & Process Research Institute (CSIR), Bhopal (MP) India*

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## ABSTRACT

*This study has been carried out to investigate the effect of shank geometry on draft requirement under simulated conditions. Experiments were conducted in a soilbin sizing L:W: H as 16.0 : 2.5 : 1.0 m. The shank geometry was varied with respect to bend angle and bend length. Bend angles of $0^0$, $15^0$, $30^0$ and $45^0$ and bend lengths of 150, 200 and 250 mm were used in experimentation in the soilbin under uniform conditions, at 50, 100, 150 and 200 mm depth levels. Using the experimental results, the bend angle and bend length were parametrically optimized for the shank of duckfoot cultivator. A significant increase in draft was observed for all the shanks with increase in tillage depth. Shank with $30^0$ bend angle and 200 mm bend length gave minimum force at all depth of operation, as compared to other shanks.*

**Key Words** : Cultivator; Shank; Soilbin; Draft; Bend angle.

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## INTRODUCTION

The duckfoot sweep cultivator (Fig.1) is used for primary and secondary tillage operations. It manipulates the soil at shallow depth to prepare seed bed for sowing. It consists of main frame, shank to which the sweep (Soil working blade) is attached and three point hitch system. The equipment is mounted to the tractor with three point hitch and operation in the field is controlled through hydraulic system of the tractor. The equipment is generally available in two sizes depending on the number of sweeps as five or seven. The most common size of sweep used are 350-450 mm. The equipment weighs 150-200 kg and costs around ` 10,000-12,000/-.

It shatters the soil without complete inversion and burial or mixing of surface material i.e. weeds, crop residues etc. In the process, the shank and sweep are loaded due to soil resistance causing bending in shank and abrasion on sweep surface. Bending of shank is most common problem observed in duckfoot sweep cultivators during field operations. The survey of agricultural machinery manufacturers showed that almost all manufacturers are using mild steel plate or flat of size ranging between 60X32 to 65X32 mm for making shank.[1]. The shank is made into required shape and size by gas cutting from thick mild steel plate. Generally no heat treatment is given to increase its strength, toughness and wear resistance. The sections are generally heavier which leads to increase in draft and costs. The weight of these shanks ranges between 9.5-12.5 kg. Despite being heavier, bending (backward and lateral) and twisting of shanks occurs frequently in duckfoot cultivators which leads to poor soil tilling. This results into lower field performance due to untilled area left in between shanks and it affects the initial establishment growth and yield of crop. The likely reasons for lower performance of duckfoot sweep cultivator may be attributed to improper design and selection of materials.

**Fig. 1 Tractor drawn duckfoot sweep cultivator**

The loads applied by the soil on the components of a cultivator are large and often difficult to predict. This difficulty of prediction of forces and lack of technical information required to optimize the size and shape of critical components results in over designing of tillage equipment. Knowledge of quantum and direction of the reaction forces is essential for optimizing the design. The magnitudes of horizontal and vertical forces acting on tillage implement are deciding factor in selecting suitable size of the implement and the size of the tractor (hp) to be used for field operation. Appropriate selection of tractor and matching implements could minimize ownership cost and operating cost of both tractor and equipment.

The growth rate in population of selected agricultural machinery have been as 10-13 % for tillage equipment like plough and harrows, 18 % for seed drills and 14 % for cultivator. [2]. Various cultivator designs are prevalent in different parts of India. However, there is little information available from the manufacturers on the benefits associated with their design aspect. Accordingly, the knowledge of the effect of cultivator shank design aspect on horizontal and vertical forces is important in guiding local manufacturers to improve the design of cultivator.

*Review*

An analysis of forces on cultivator sweeps and spikes was carried out by Kiss et al. It was shown that draft forces increased with depth of tillage and so did the vertical forces. Cultivator sweep of 400 mm width was tested in five different sites having slightly varying clay content. The forces were measured with the help of six-load cell dynamometer. It was observed that the draft of trailing sweep was 27 % less than that measured on the leading sweep. The variation in vertical force was reported to be increasing with the increasing depth. The vertical force was usually found to be directed downward. The variation in lateral force with increasing depth was observed to be nearly nil for leading sweep. The effect of soil composition on draft was also observed by the investigators and it was found that the draft increased with the increasing clay content.[3]. El-Sayed studied the effect of shank shape, shank material and shank cross-section on draft requirement of a chisel plough. The tests were carried out at different levels of forward speeds, ploughing depths, and rake angle and it was found that the curved shank chisel plough performed better compared to straight shank chisel plough.[4]. Upadhyaya et al. reported that the draft force depended on soil conditions and the geometry of tillage implement.[5]. Al-Janobi et al. studied the influence of shank shape of three common chisel ploughs (Semi-straight, semi-curved and curved shank) operating on a sandy loam soil under different levels of forward speed and ploughing depth, on horizontal and vertical force requirements. The curved shank was observed to have given higher horizontal and vertical force compared to the other two shanks when operated at different forward speeds. Significant increase in horizontal force was observed for all chisel ploughs and was proportional to increase in the forward speed. However, no significant increase in vertical forces was observed for all the three ploughs with an increase in the forward speed.[6]. An investigation was conducted to develop and validate a novel approach for prediction of draft required by primary tillage implements operating in field conditions, by Desbiolles JMA et al. They developed a force prediction model which described the draft of standard tine as the product of two factors, related to soil strength and tool geometry respectively. The tool index relationships were determined under laboratory conditions for number of tillage tools at different working depths and the methodology was validated in four field conditions, two friable sandy loams, compact clay and plastic clay soil. Predicted drafts were on average within 18% of the measured values. The average prediction errors for tine tools, moldboard ploughs and disc tools were 14,16 & 30% respectively, in friable soil conditions.[7]. Gupta studied the influence of tool design and tillage system parameters on performance of wide cutting blades for dry land farming. He found that specific draft increased with radius of curvature from 410 to 600 mm, whereas the same decreased in curvature range of 700 to 1000 mm.[8]. The lead angle provided in shanks, affects the soil tilling [9,10].

Review of published work shows that many studies have been conducted and models have been developed to study the design aspect of soil cutting blades of different types of equipment like Subsoiler, Moldboard Plough, Cultivator, Disk Implements. Implement width, depth of operation, speed of operation, and rake angle are the factors that affect the horizontal and vertical forces acting on an implement. The studies conducted so far lacked the details of geometrical variability in shanks like the effect of lead angle, width of shank, quantified shank curvature and the like. Little is known of effect of shank geometry on performance of a tined implement. The objective of the investigation is therefore to measure the effect of shank geometry so as to provide guideline for tillage tool designers and users. Using this approach, the bend angle and bend length are parametrically optimized for the shank of duckfoot cultivator.

## MATERIALS AND METHODS

### Soil Bin System

While optimizing tillage equipment, study of soil-tool interaction may be highly error-prone because of different conditions, mechanism and variables involved. This becomes more and more complex during the process as the behaviour of soil varies even with a slight change in moisture content, compaction level, type of soil minerals or particle size distribution and arrangement. The soil media therefore need be so prepared and controlled that it offers same condition for all treatments without causing any error because of above mentioned parameters.

The experiments under simulated conditions were conducted in the soil bin facility at Central Institute of Agricultural Engineering, Bhopal, India. The size of the bin L:W: H was 16.0 : 2.5 : 1.0 m which holds enough soil volume to facilitate testing of full size equipment without side effects and variability. The tool to be tested is mounted on carriage unit, which is powered by a 15 kW advanced variable speed (AVS) drive. The variable speed and auto-reversing carriage also serves as mounting unit for signal conditioners and sensors. The carriage can be accelerated to the speed equivalent to the field operational speed of all implements, by varying rpm of AVS drive with a click of mouse, thus making it variable speed carriage. The soil processing unit included roto-tiller, deep working tines, sheep fool roller, soil leveler and water application system to obtain uniform moisture, density and penetration resistance throughout for each experiment with repeatability measures.

The soil bin instrumentation system consisted of electronic measuring, computing and analysis system to evaluate the performance of equipment. A control desk facilitated remote operation of carriage, data logging and analysis. The instrumentation system included six load cells for measurement of horizontal, vertical and lateral forces acting on a tool in operation, linear speed sensor for measurement of operational speed of tool. A penetrologger to measure the compaction level at different stages. The complete force system can be measured on mounted equipment with the force measurement system. It consisted of a sub frame, which was entirely supported from the carriage through six appropriately oriented force transducers. The implement could be mounted on the sub frame and the three mutually perpendicular forces acting on it during operation can be measured with the help of six S-type load cells (2 each of 3000, 5000 and 10000 N). Three vertically mounted load cells measured vertical force, two horizontally mounted load cells measured horizontal force or draft and one mounted on the side measured lateral force. All six load cells were calibrated for both tensile and compressive loading. With such an arrangement, loads having any combination of translational and rotational soil reaction can be tested while parameters such as speed, working angle of tool, depth of operation or width of cut etc. are varied. Soilbin and tool testing set-up is shown in Fig. 2.

The core of the complete soil bin system is computer controlled data acquisition and analysis unit. It is supervisory control and data acquisition (SCADA) and programmable logic control (PLC) based system. The computer based acquisition and control system provide on–line display and logging of experimental variables while simultaneous preparation of reports in printable format which allows rapid evaluation of experimental results. Sensors fitted at appropriate locations gets the variable input in analog / digital form and send them to signal conditioners fitted on the carriage. The signal conditioners amplify the input signal and further transmit them to the programmable logic control (PLC) unit installed in the control desk in control room. The PLC unit analyzes and displays the results on computer screen through SCADA. The SCADA also enabled remote control of carriage operation from the control desk. During on-line display, data is also logged in MS Access format in the same computer.

**Treatments and experimental procedure**

Tests were conducted for ten geometrical configurations of shank as shown in Fig. 3 and 4 (a,b,c). A straight shank having bend angle as $0^0$ was utilized as control treatment. All shanks were fitted with a wide blade (width = 400 mm) and operated at actual field speeds for tillage, i.e. 0.7 m/s. The total length of shank was maintained as 500 mm at all bend lengths and bend angles. For each experiment, the desired shank was fitted in the soil bin carriage and at the soil was processed to uniform conditions so as to avoid any error due to change in soil conditions. For each shank experiments were conducted at 50, 100, 150 and 200 mm depth, at the same speed. As the tool carriage and hence the tool moved through the soil, the instrumentation system acquired the force and speed data from the sensors mounted on the carriage. The instrumentation system acquired force data (draught i.e. horizontal force, Fx and vertical force, Fy) simultaneously and continuously.

## RESULTS AND DISCUSSION

The mean values of observed draft and vertical force at different bend angle, end length and depth of operation are given in Table 1. The analysis of observed values of draft and vertical force corresponding to different variables is also presented in Table 2. The analysis showed that the effect of design parameters of shank and operational variables and their interactive effect on draft and vertical force was significant. The results can be critically analyzed under following heads:

### Effect of bend angle

The effect of bend angle on draft requirement at different bend length and depth of operation is shown in Table 1 and Fig. 5. Effect of bend angle is dominant at higher depths of operation. At all depth of operation, the draft was observed to be minimum for $30^0$ bend angle. At all depth of operation , the draft was found to be increasing for $15^0$ bend angle, except for 200 mm bend length and decreasing for $30^0$ bend angle. At $45^0$ bend angle, the draft forces tend to increase again at higher depth of operation. The difference between draft values at $30^0$ and $45^0$ bend angles was not significant. The effect of bend angle on vertical force also showed the similar trend. Bend angle of $30^0$ exhibited minimum vertical downward force.

**Table 1: Draft and vertical force values at different bend angle, bend length and operational depths**

| Depth (mm) | Bend Angle (Degree) | Draft (N) | | | | Vertical Force (N) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Bend Length (mm) | | | | Bend Length (mm) | | | |
| | | 0 | 150 | 200 | 250 | 0 | 150 | 200 | 250 |
| 50.0 | 0.0 | 29.9 | -- | -- | -- | 23.8 | -- | -- | -- |
| | 15.0 | -- | 49.7 | 25.6 | 31.0 | -- | 28.4 | 23.5 | 16.8 |
| | 30.0 | -- | 40.8 | 22.1 | 34.3 | -- | 25.1 | 18.9 | 26.7 |
| | 45.0 | -- | 38.0 | 24.0 | 32.2 | -- | 21.1 | 22.6 | 22.5 |
| 100.0 | 0.0 | 64.2 | -- | -- | -- | 44.3 | -- | -- | -- |
| | 15.0 | -- | 114.4 | 62.4 | 76.4 | -- | 66.8 | 38.7 | 43.1 |
| | 30.0 | -- | 83.6 | 56.7 | 80.1 | -- | 54.4 | 35.2 | 47.8 |
| | 45.0 | -- | 79.4 | 58.7 | 72.9 | -- | 49.2 | 39.3 | 53.9 |
| 150.0 | 0.0 | 143.9 | -- | -- | -- | 86.3 | -- | -- | -- |
| | 15.0 | -- | 190.7 | 138.3 | 154.5 | -- | 120.3 | 82.4 | 68.9 |
| | 30.0 | -- | 153.1 | 122.6 | 157.9 | -- | 103.7 | 68.1 | 89.7 |
| | 45.0 | -- | 145.1 | 119.8 | 175.3 | -- | 75.7 | 81.0 | 105.8 |
| 200.0 | 0.0 | 266.9 | -- | -- | -- | 149.2 | -- | -- | -- |
| | 15.0 | -- | 326.8 | 264.2 | 274.0 | -- | 156.5 | 145.1 | 144.0 |
| | 30.0 | -- | 281.1 | 228.8 | 299.0 | -- | 129.1 | 131.0 | 159.2 |
| | 45.0 | -- | 258.9 | 237.3 | 307.1 | -- | 133.2 | 182.3 | 174.6 |

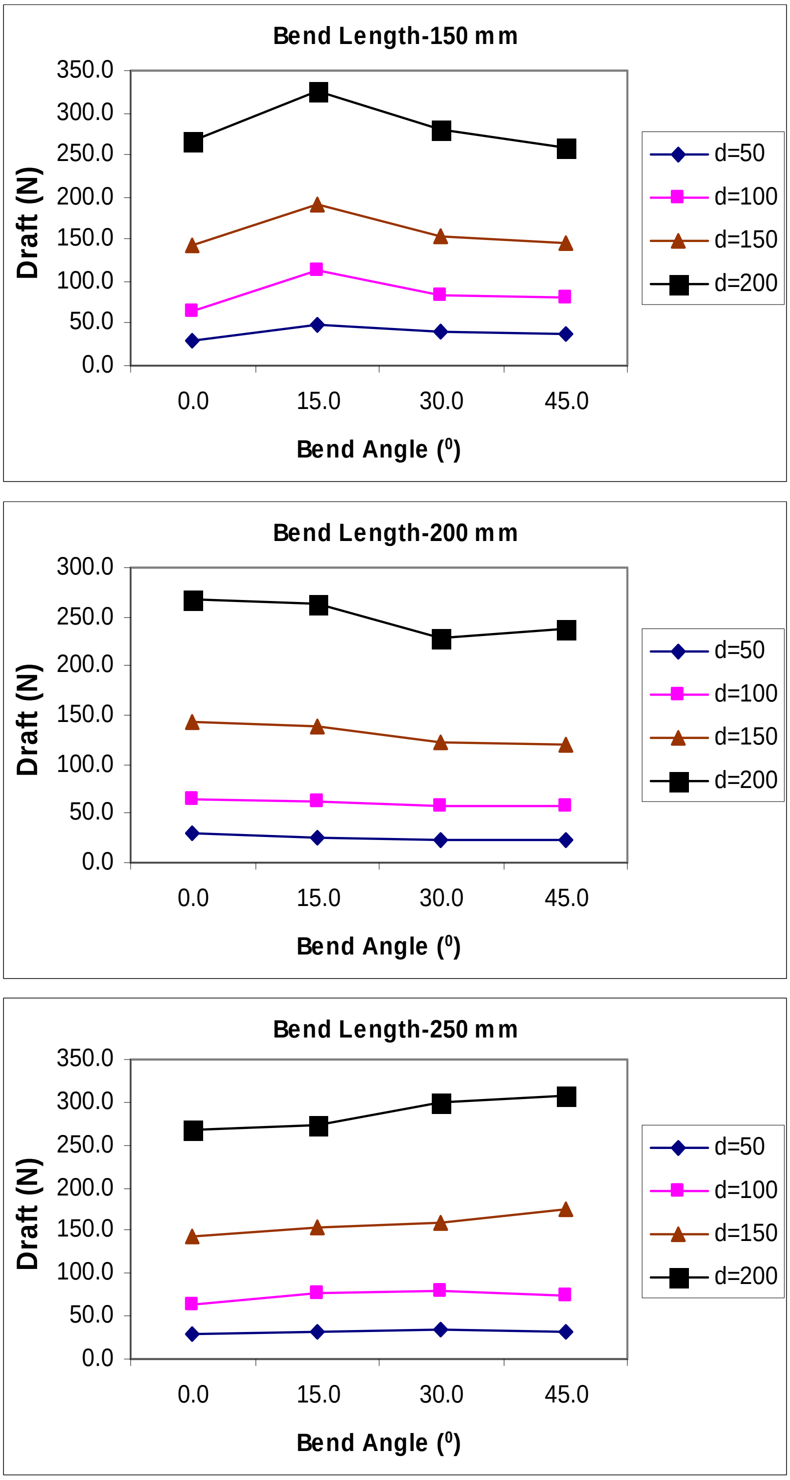


**Fig.5: Effect of bend angle on draft at different bend length and depth of operation**

| Table 2 : Analysis of variance for effect of bend angle, bend length and operating depth of shank on draft | | | | | |
|---|---|---|---|---|---|
| Source | SS | df | Mean Square | F | Sig. |
| Corrected Model | 5310791.23 | 112 | 47417.78 | 601.3603882 | 0 |
| Intercept | 11348414.80 | 1 | 11348414.80 | 143922.5392 | 0 |
| REP | 1893.53 | 2 | 946.76 | 12.00701822 | 0.00 |
| Bend Angle (α) | 26968.52 | 3 | 8989.51 | 114.0064676 | 0 |
| Bend Length (ℓ) | 67202.38 | 2 | 33601.19 | 426.1360688 | 0 |
| Width (w) | 44019.43 | 3 | 14673.14 | 186.0873019 | 0 |
| Depth (d) | 5055149.28 | 3 | 1685049.76 | 21370.08953 | 0 |
| α x ℓ | 48507.93 | 6 | 8084.65 | 102.5309766 | 0 |
| α x w | 16333.29 | 9 | 1814.81 | 23.01573102 | 0 |
| α x d | 9221.35 | 9 | 1024.59 | 12.994083 | 0 |
| ℓ x w | 2334.10 | 6 | 389.02 | 4.933576513 | 0.00 |
| ℓ x d | 11375.11 | 6 | 1895.85 | 24.04351417 | 0 |
| w x d | 7484.08 | 9 | 831.56 | 10.54604201 | 0.00 |
| α x ℓ x w | 7825.44 | 18 | 434.75 | 5.513528262 | 0.00 |
| α x ℓ x d | 11020.24 | 18 | 612.24 | 7.764478541 | 0 |
| ℓ x w x d | 1456.55 | 18 | 80.92 | 1.026232532 | 0.43 |
| Error | 36507.94 | 463 | 78.85 | | |
| Total | 16695713.97 | 576 | | | |
| Corrected Total | 5347299.17 | 575 | | | |
| a | R Squared = .993 (Adjusted R Squared = .992) | | | | |

**Effect of bend length**

At all levels of depth of operation, the mean values of draft were observed to be highest for 150 mm bend length and lowest for 200 mm bend length, as shown in Fig. 6. The draft requirement for 250 mm bend length was found to be higher in comparison to 200 mm bend length, at all depth of operation. The vertical downward force was also found to be minimum for 200 mm bend length at all depth of operation, in comparison to straight shank and shanks having 150 and 250 mm bend length.

**Interactive effect of bend length and bend angle**

The interactive effects of bend angle with bend length, bend angle with operating depth and bend length with operating depth on draft are presented in Table 2. The response of horizontal force as affected by changes in bend length and bend angle is illustrated in Fig.7 for different depths of operation. The results showed an increase in horizontal and vertical force both, in all treatments, with the increasing depth of operation. At all depth of operation the horizontal force (draft) was found to be maximum for 150 mm bend length and $15^0$ bend angle. The lowest value of horizontal force was observed in case of 200 mm bend length and $30^0$ bend angle. The horizontal force values for 200 mm bend length and $30^0$ bend angle shank were found to be 22.1, 56.7, 122.6 and 228.8 N at 50, 100, 150 and 200 mm depth respectively, these were 55, 50, 35 and 30% lower in comparison to horizontal force values for 150 mm bend length and $15^0$ bend angle at the respective depth of operation.

Comparing the draft requirement of 200 mm bend length shank to that of 250 mm bend length shank, for the same $30^0$ bend angle, it was observed that the 200 mm bend length shank exerted 30-36 % less draft force up to 100 mm depth of operation. Between 100-200 mm depth of operation, the draft requirement of 200 mm bend length shank was observed to be 22-24 % lower in comparison to 250 bend length having same bend angle.

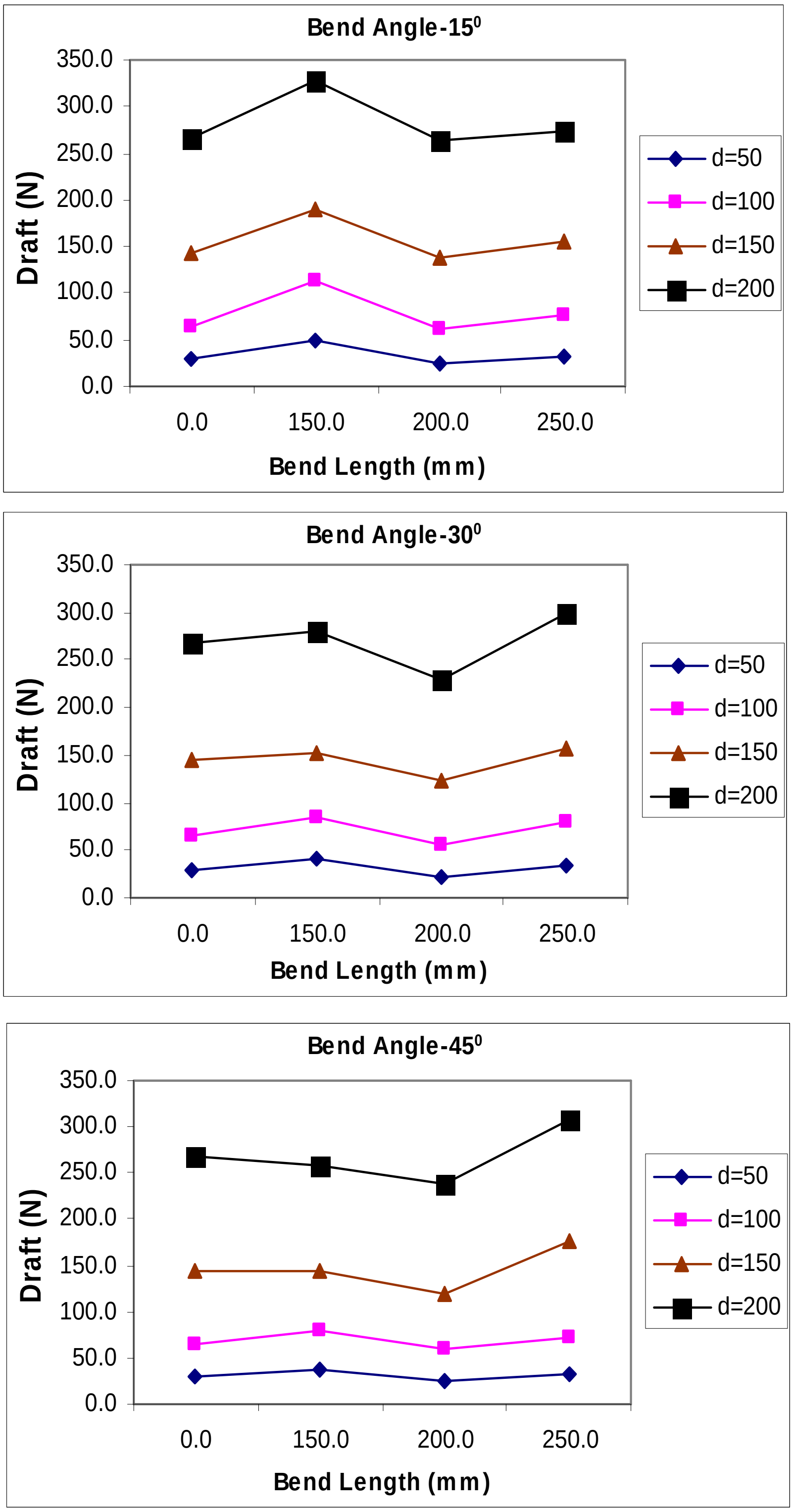


**Fig. 6: Effect of bend length on draft at different bend angle and depth of operation**

The draft requirement of 200 bend length shank with $30^0$ bend angle in comparison to $45^0$ bend angle having same bend length was also found to be lower in the range of 22 to 31 % at different depths of operation.

The overall interactive effect (α x ℓ) on draft was significant at 1 % level. Three variable interaction (α x ℓ x w) on draft was also significant at 1% level.

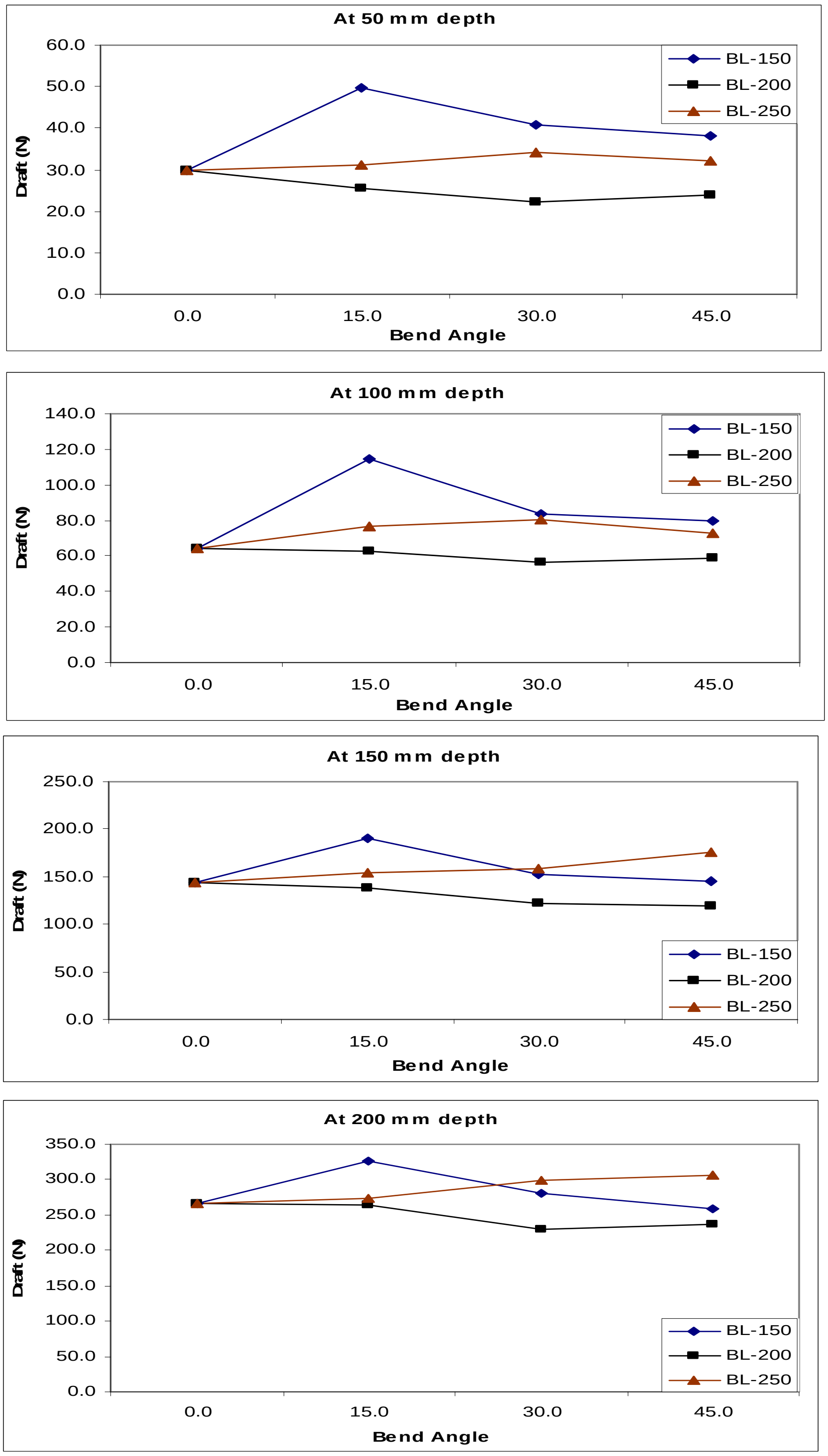


**Fig.7: Effect of bend length and bend angle on draft**

## CONCLUSION

An increase in horizontal and vertical forces was observed with increasing depth for all experimental shanks having different bend length, bend angle and width. The analysis of variance showed that the effect of design parameters of shank and operational variables and their interactive effect on draft and vertical force was significant. Lateral forces were found to be negligible or non-existent.

On the basis of minimum draft requirement, the optimum values of bend length and bend angle for cultivator shank were found to be 200 mm and 300 respectively. The width of shank was optimized as 35 mm, considering the advantage of width in minimizing the lateral bending of shank which may occur due to accidental lateral forces at the time of turning.

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