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Determination of angle of penetration of soil working tools in clay soil

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The failure of soil by tillage tool is caused by shearing, compression, impact or vibrations resulting in cutting or crumbling of the soil. The main active part of almost all tillage tools is the cutting edge. Factors such as the shape of the cutting edge, material of construction, action of the tool, depth of operation and forward speed in addition to the soil physical properties have a great effect on the soil failure. The angle of penetration of cutting edge (lift angle) is one of the important parameters which greatly affect the draft requirement of any tillage equipment. Zhang and Araya (2001) reported that the draft had increased steeply when the cutting angle was more than 30° in mould board plough and was unsuitable for practical use in meadow soil of Black Dragon of China. Varshney and Patel (1988) reported that the effect of cutting angle of shovel of a cultivator on unit draft and penetration at different soil moistures in light soil of north Gujarat was minimum draft of shovel at 30° cutting angle. Gill (1969) suggested that the force required for the penetration of steel wedge shaped tool was minimum at 50° tool tip angle and 25° angle of inclination of tool working surface. Kawamura (1952) found the minimum draft force at a lift angle of about 25° for shallow depth of operation. However, no work has been reported about the optimum degree of penetration of tillage tools under actual field condition with clay soil. Therefore, an experiment was conducted to study the effect of angle of penetration of share of a mould board plough and sweep on draft requirement with two soil moisture contents and to optimize the angle of penetration on the basis of minimum draft.

One experiment was conducted at Central Institute of Agricultural Engineering, Bhopal during 2001 to study the effect of angle of penetration of share of a 20 cm size mould board plough and a 30 cm size sweep (Fig 1) with bevel angle of 15°. Two levels of soil moisture contents were taken for mould board plough (22 and 18.5%) and sweep (21 and 18%) to study as the mould board plough and sweeps are normally operated in this range of soil moisture. The texture of the soil was clay with 55% clay, 30% silt and 15% sand. The mould board plough bottom and sweep were mounted on a frame of cultivator on the rear side of the power tiller. The power tiller was operated in second low gear with an average speed of 1.35 km/hr. The angles of penetration were varied by inserting wedges of different angles of 2, 4, 6 and 8° between rear gang of cultivator frame and the upper part of the shank. Nine angles of penetration in the range of 15 to 31° for mould board plough and 19 to 33° for sweep were used (Table 1). Bulk density of soil and the cone index were measured for each test. The cone index of the field soil was 911.8 kPa at a soil depth of 140 mm.

Table 1 Details of field condition and variables

Treatment	Tools	Moisture content of soil (%)	Bulk density of the soil (g/cc)	Angles of penetration of tillage tools
T_1	MB Plough Share	22.00	1.28–1.30	9 (15–31°)
T_2	MB Plough Share	18.50	1.28–1.30	9 (15–31°)
T_3	Sweep	21.00	1.28–1.30	9 (19–33°)
T_4	Sweep	18.00	1.28–1.30	9 (19–33°)

The draft and the cross sectional area of the furrows were measured to determine the unit draft. A 250 kg load cell with digital indicator with a least count of 1 kg was used to determine the draft (Fig 2). The load cell was mounted between the hitching point of the implement and the power tiller hitch in such a way that it remains horizontal during operation of power tiller. Forty readings of draft were recorded for each test and average was taken for presentation. The shape of the furrow made by mould board plough was trapezoidal while the shape of furrow was triangular for sweep. The width and depth of the furrows were measured at fifteen places and average was taken. The cross sectional area of the furrows was calculated. The unit draft was worked out by dividing draft by average cross sectional area of furrows.

The observations of the shape of the furrows showed that the furrows made by the mould board plough were trapezoidal with slightly rough surfaces due to non-uniform failure of soil (Fig 3). The observations of unit draft showed that the value of unit draft decreased up to 0.40 kg/cm² and then increased sharply with the change in angle of penetration.

*Short note

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The relationship between unit draft, k (kg/cm^2) and angle of penetration, q (degrees) was a quadratic equation with a high coefficient of determination (R^2) and highly significant F value for all four treatments (Table 2).

Table 2 Mathematical correlation between unit draft and angle of penetration

Treatment	Predicted equation	R^2 (coefficient of determination)	'F' value
T_1	$k = 0.0026^{**}q^2 - 0.1142^{**}q + 1.6079^{**}$	0.96	1828^{***}
T_2	$k = 0.0016^{**}q^2 - 0.0726^{**}q + 1.1872^{**}$	0.93	2962^{***}
T_3	$k = 0.0019^{**}q^2 - 0.1067^{**}q + 2.1240^{**}$	0.89	5007^{***}
T_4	$k = 0.0030^{**}q^2 - 0.1609^{**}q + 2.7463^{**}$	0.91	2601^{***}

**Significant at 5% level, ***significant at 1% level

It was observed that minimum unit draft was 0.40 kg/cm^2 at 22% soil moisture content for mould board plough while the minimum unit draft of 0.35 to 0.39 kg/cm^2 was observed at soil moisture content of 18.5% for 21 to 25^0 angle of penetration (Fig 4). The reason for this behaviour may be attributed to the probable plane of soil failure at angle of 21 to 25^0 with horizontal for clay soils. However, at lower soil moisture content of 18.5%, the unit draft was less (0.35 to 0.39 kg/cm^2) as compared to higher level of moisture content due to more adhesion of moist clay soil with the surface of the tool at higher moisture content.

The results of measurement of unit draft of the sweep of 30 cm size showed the variation in minimum unit draft of 0.62 to 0.72 kg/cm^2 at angles of penetration of 25 to 29^0 at soil moisture content of 21.0%, whereas the values of the minimum unit draft varied from 0.60 to 0.63 kg/cm^2 at 18.0% soil moisture content. The slight variation in the angle of penetration for mould board plough and sweep may be attributed to the effect of design of the cutting point which actually causes the failure of the soil. It may also be seen from the data of unit draft of sweep that there was not much variation in the unit draft at 21% and 18% soil moisture simply because the simple construction of sweep may not affect sticking of soil on the surface at these two soil moisture contents.

The observations of the unit draft indicated that the design of mould board plough is better as compared to sweep for opening the furrows and requirement of power for seed bed preparation.

SUMMARY

One experiment was conducted to study the effect of angle of penetration of share of a 20 cm size mould board plough and a 30 cm size sweep with bevel angle of 15 degrees at two levels of soil moisture content 22 and 18.5% for mould board plough and 21 and 18% for sweep. Minimum unit draft of 0.40 to 0.41 kg/cm^2 was found with penetration angle of 21 to 25^0 for mould board plough. The minimum unit draft of 0.62 to 0.72 kg/cm^2 was found with angles of penetration of 25 to 29^0 with the sweep at soil moisture content of 21%. At lower soil moisture content of 18.5% the unit draft was less (0.35 to 0.39 kg/cm^2) as compared to higher level of moisture content due to more adhesion of moist clay soil with the surface of the components of mould board plough at higher moisture content (22.5%). The observations of unit draft showed that the design of mould board plough is better than the design of sweep in terms of requirement of power for opening the furrows in the field for seedbed preparation.

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