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Effect of radius of curvature and spading frequency of spading machine on physical properties of soil

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■ **ABSTRACT :** The effect of radius of curvature and spading frequency on various dependent variables, *i.e.* weighted mean clod size, soil bulk density, cone index and cone index ratio were studied. The experiments were conducted in soil having 15.7 per cent clay, 53.6 per cent silt, and 30.7 per cent sand. During experimentation, moisture content of soil was maintained between 13 and 14 per cent. The radius of curvature used were C1 (Flat), C2 (15 cm) and C3 (30 cm). Four levels of bite lengths *viz.,* 4, 6, 8 and 10 cm at travel speed of 18.47 cm/sec were selected for the study. These corresponded to four levels of spading frequencies namely F1 (1.85 cycles/s), F2 (2.31 cycles/s), F3 (3.08 cycles/s) and F4 (4.62 cycles/s). The spading frequency was determined by dividing the travel speed by the bite length. The dependent variables decreased with increase in radius of curvature and spading frequency. Weighted mean clod size, soil bulk density and soil cone index decreased with increase in spading frequency and radius of curvature. However, it increased with increase with blade width.

■ **KEY WORDS :** Spading machine, Tillage, Radius of curvature, Spading frequency, Pulverization, Bulk density, Cone index

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Tillage is a major farming operation for seedbed preparation. Tillage involves various physical actions but most important is breaking apart of the monolith soil surface (Singh and Singh, 1986). Energy required to force a tillage tool through the soil is used to overcome the mechanical strength of the soil and to cause displacement, which resulted in compaction or break-up (Gill, 1969). Rotary tillers are popular machines for tillage in one go. But, the rotary tillers consumed more energy than conventional tillage implement. However, degree of pulverization or tillage efficiency varied considerably in terms of seed germination with these tillage tools. Spading machines could be an alternative. Spading machine is a PTO driven implement designed to approximate the effect of proven smaller-scale hand digging tool for the purpose of deeper aeration, and effective integration of organic matter. It has been claimed that their action subtly aerated/fractured the subsoil twice the depth of the stroke of the spades (Palmer, 2002). The advantage of this machine had been that it did not form any hardpan as the path of the tools in the soil is never parallel to the soil surface. An attempt had been made to develop a spading machine having non interactive tool path of blade back surface with uncut soil (Sambhi, 2006). The machine was evaluated with straight flat blades whereas the manual spades consisted of a long stick and a small blade with different shapes and angle that had been used for tillage purpose through ages. Soil bin studies were carried out to define the effect of blade widths and spade angle (Bishnoi, 2008). The spade angle is also an important factor. It is expected to reduce initial impact thereby reducing energy requirement for spading. So, this study was conducted to study the effect of spade angle and spading frequency on performance of spading machine.

■ METHODOLOGY

Development of laboratory models of spading machine:

The dimensions of four bar linkage of the laboratory model of spading machine (Fig. A) were derived from the research prototype of spading machine developed at Punjab Agricultural University (PAU), Ludhiana. The blades of different combinations were got fabricated and blade assembly was mounted on the coupler extensions on the lower rectangular frame of the tool-trolley. The experimental blades consisted of blades of different blade width (W1 and W2), spade angle (A1, A2 and A3) and radius of curvature (C1, C2 and C3).

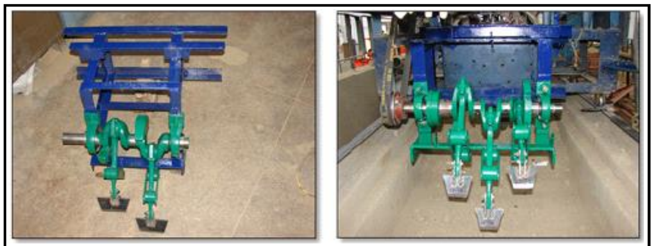

Fig. A : View of laboratory models of spading machine

Soil:

The experiments were conducted on cultivable soil having 15.7 per cent clay, 53.6 per cent silt and 30.7 per cent sand in the soil bin.

Experimental design and methods:

Factorial Randomized Block Design was selected to conduct the experiments and to analyze the effect of the study variables. Each experiment was replicated thrice. The effect on various dependent variables *i.e.* weighted mean clod size, soil bulk density, soil cone index and cone index ratio had (Ratio of sum of area of cone index initial divided by sum of area of cone index after treatment) been studied.

There were three radius of curvtaure (Fig. B), two spade widths and four spading frequencies with three replications: C1 (Flat), C2 (15 cm) and C3 (30 cm). F1 (1.85 cycles/s), F2 (2.31 cycles/s), F3 (3.08 cycles/s) and F4 (4.62 cycles/s).

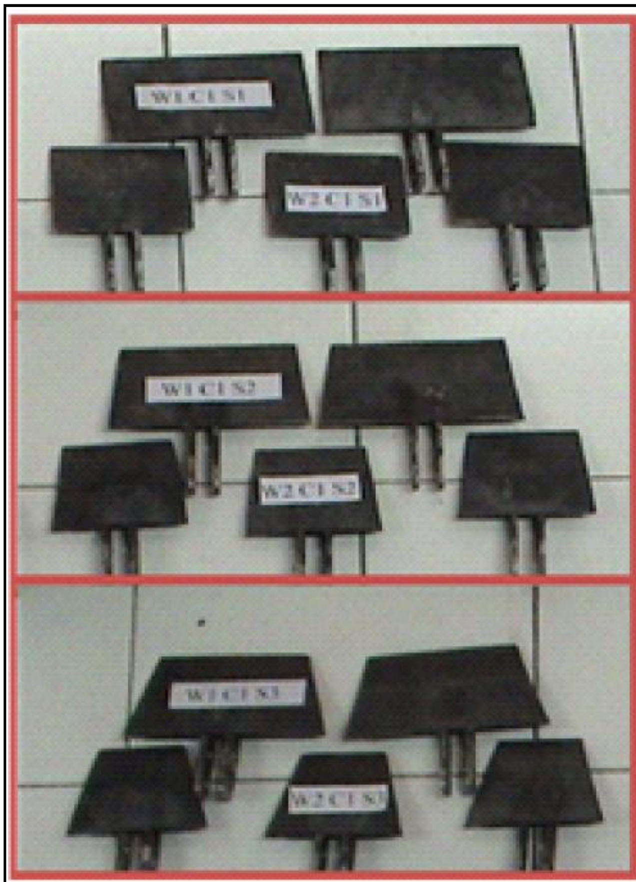

Fig. B : Views of spading blades used the study

Measurement of radius of curvature:

Radius of curvature of the two spades used measured using graphical method (Fig. C) described by the White (1918). A fixture was fabricated for the measurement of radius of curvature (Fig. C). Three radii

Fig. C: Views of fixture fabricated for measurement of radius of curvature of spade

of curvatures were selected in the previous section. Similarly three spade angles and two blade widths were also selected as in the previous section.

Soil bulk density:

Soil bulk density was determined before and after tillage treatments using core samples drawn randomly from the individual test plots.

Weighted mean clod size:

The clod size distribution was expressed in terms of mean mass diameter (MMD) calculated in accordance with the procedure explained in the Test Code and Procedure for Rotary Tillers (Part 2) (RNAM, 1983) as given below.

$$MMD = 1/W\ (D_1A + D_2B + D_3C + \text{——} + D_nN)$$

where MMD is mean mass diameter of soil clods; D_1, D_2, D_3, ——, D_n is representative diameter of soil clods retained on a particular sieve; A, B, C, —, N is mass of soil retained on a particular sieve; W is total mass of soil sample.

A set of sieves for sieve analysis included 100, 63, 40, 20, 10, 4.75, 2, 1, 0.600, 0.425, 0.212, 0.150 and 0.075 mm sizes. Samples were drawn from a sufficiently large area of each test plot to give a representative value for MMD.

Soil cone index:

Soil cone index was determined (Fig. D) to measure penetration resistance of the soil before and after applying various treatments at working section of the soil along the length of soil-bin.

Fig. D: Set-up for measuring cone index in a soil bin

Soil moisture content:

Soil moisture content was determined gravimetrically. Samples were obtained using core sampler and oven dried at 105^{0}C for 24h. During experimentation moisture content of soil was maintained between 13 and 14 per cent by adding calculated amount of water in the soil.

Seed-bed preparation in soil-bin:

Soil in the soil-bin was prepared first with six passes of roto-tiller and levelled by a levelling blade after each pass. Finally, it was levelled by a wooden leveller after six passes of roto-tiller. The soil was then compacted and soil cone index and soil bulk density were recorded. Soil profile density was recorded before operating the laboratory model of spading machine. The soil profile density varied from 1.4 to 1.6 Mg/m^3 with standard deviation of 0.04. The laboratory model of spading machine mounted on crankshaft was run ideally as show in Fig. E.

Fig. E : View of compressor, pneumatic cylinders and controls used for tool carriage

■ RESULTS AND DISCUSSION

The experiments were conducted on soil having 15.7 per cent clay, 53.6 per cent silt and 30.7 per cent sand. During experimentation moisture content of soil was maintained between 13 and 14 per cent. The effect of different radius of curvature and spading frequencies on various dependent variables, *i.e.* weighted mean clod size, soil bulk density and soil cone index were found to be inversely related *i.e.* increase in radius of curvature caused decrease in various dependent variables.

Effect of radius of curvature on weighted mean clod size:

It was evident Fig. 1 that weighted mean clod size decrease with increase in radius of curvature. In blade width W1 radius of curvature was maximum for combination C1F1 (9.28mm) and it was minimum for combination C3F4 (1.71mm). Further with increase in spading frequency weighted mean clod size decreased. It indicated that as radius of curvature increased weighted mean clod size decreased and with increase in spading frequency weighted mean clod size decreased. This information has been plotted in Fig. 1. The trend curves also plotted and regressed. Trend curves had linearly decreasing nature as best fit. However, at higher spading frequency the effect of curvature diminishes.

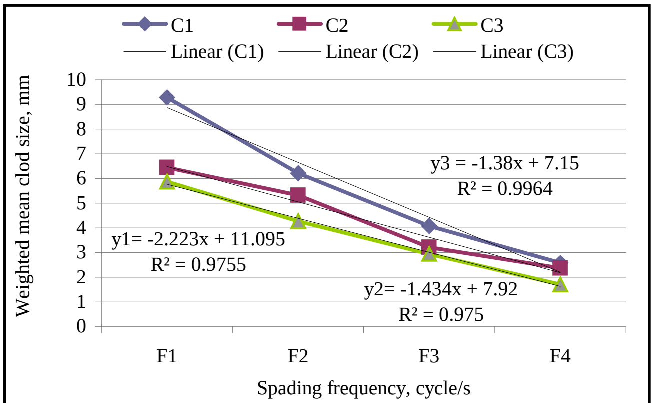

Fig. 1 : Effect of different radius of curvature on weighted mean clod size at blade width W1

It was evident Fig. 2 that radius of curvature for blade width W2 was maximum for combination C1F1 (14.35 mm) and it was minimum for combination C3F4 (1.90 mm). Further with increase in spading frequency weighted mean clod size decreased. It indicated that as radius of curvature increased mean clod size decreased also with increase spading frequency weighted mean clod size decreased. The trend curves were also plotted and regressed. Trend curves had linearly decreasing nature as best fit.

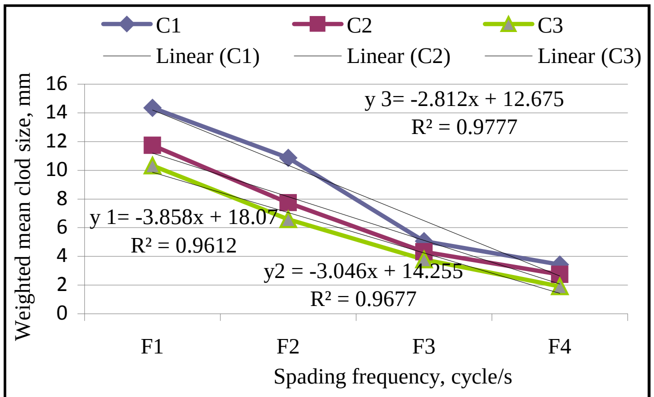

Fig. 2 : Effect of different radius of curvature on weighted mean clod size at blade width W2

The weighted mean clod size of clod decreased with increase in radius of curvature because at friable state the soil was removed as a chunk. The chunk of soil mass increased with increase in radius of curvature. On striking with flat cover the curved chunk of soil mass broke into finer pieces.

The effect of different radius of curvature on soil aggregate size distribution had been shown in Fig. 3 and Fig. 4. It indicated that soil manipulation with different radius of curvature was identical C3 gave finer soil clod size compared with C2 and C1. Thus, for blade width W1 with increase in radius of curvature weighted mean clod size decreased showing better pulverization. The co-efficient of uniformity of soil aggregate was 22.42 for C1W1, 20.74 for C2W1 and 15.50 for C3W1 radius of curvatures.

Similarly, for blade width W2 (15cm), increase in radius of curvature, mean clod size decreased showing better pulverization. Coefficient of uniformity of soil

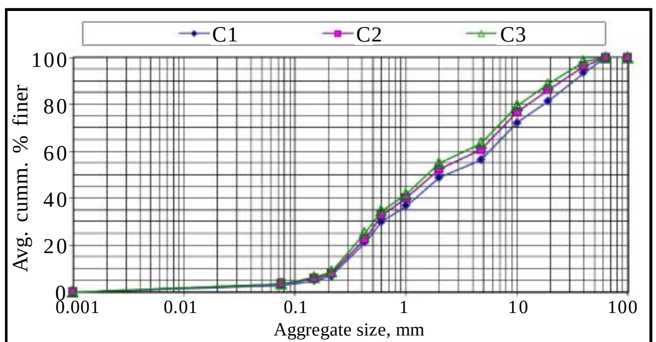

Fig. 3 : Aggregate size distribution at different radius of curvatures for all spading frequencies and spade angles at blade width W1

aggregate was 53.49 for C1W2, 45.03 for C2W2 and 25.68 for C3W2 radius of curvatures.

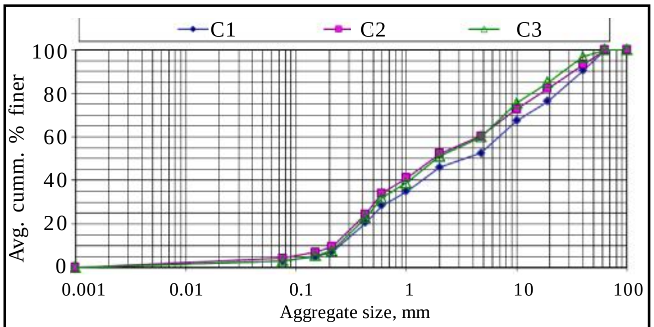

Fig. 4 : Aggregate size distribution at different radius of curvatures for all spading frequencies and spade angles at blade width W2

Effect of radius of curvature on soil bulk density:

It was evident Fig. 5 that blade with radius of curvature C3 had lesser soil bulk density as compared to radius of curvature C2 and C1. The effect of spading frequency was identical as was observed in blade width *i.e.* bulk density decreased with increase in spading frequency for different radius of curvatures. The effect of different radius of curvature for blade width W1 the maximum value of soil bulk density attained for the combination C1F1 were 1.35 Mg/m^3 indicating minimum change from initial conditions. Whereas, maximum change had occurred at combination C3F4 and value obtained were 1.24 Mg/m^3.

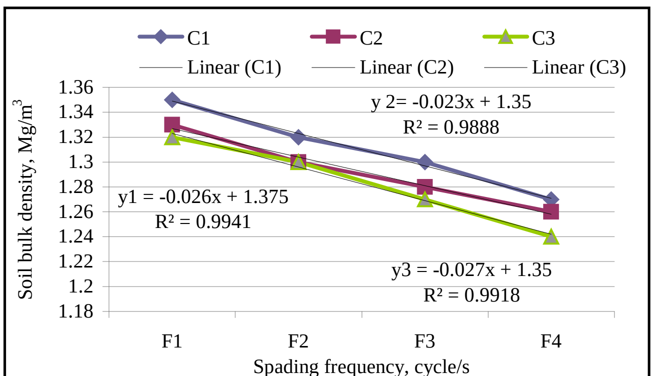

Fig. 5 : Effect of different radius of curvature on soil bulk density at blade width W1

Similarly, for blade width W2 it was evident Fig. 6 that soil bulk density was maximum for combination C1F1 (1.37 Mg/m^3) it was minimum for combination C3F4 (1.27 Mg/m^3).

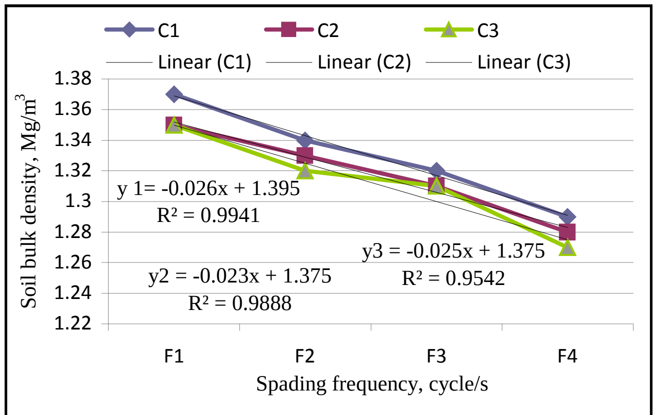

Fig. 6 : Effect of different radius of curvature on soil bulk density at blade width W2

The curvature of chunk of mass detached in spading action increased with increase in radius of curvature of blades. This curved chunk when struck with flat cover broke into smaller aggregate as compared to flat chunk. Finer aggregates settled better on fall and bulk density was less as compared to soil with bigger aggregates. Therefore, soil bulk density was lesser in case of curved blades as compared to flat blades.

Effect of radius of curvature on cone index:

The results of soil cone index for different radius of curvatures at blade width W1 and W2 have been plotted in Fig. 7 and 8, respectively. The effect of different radius of curvature for blade width W1 the maximum value of soil cone index attained for C1F1 were 0.51MPa indicating minimum change from initial conditions.

Whereas, maximum change had occurred at

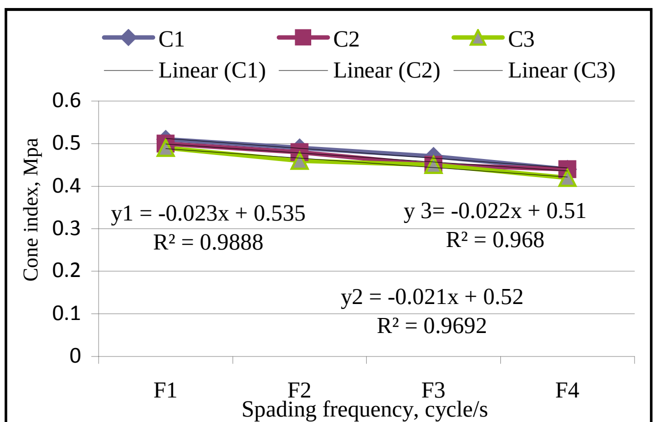

Fig. 7 : Effect of different radius of curvature on soil cone index at blade width W1

combination C3F4 and minimum value obtained was 0.42MPa for blade width W1. The results of effect of radius of curvature have been plotted in Fig. 7. The values attained were regressed and equations have been given in figure itself.

Similarly, it was evident Fig. 8 that for blade width W2 soil cone index was maximum for combination C1F1 (0.51MPa) and it was minimum for combination C3F4 (0.42MPa). The effect of spade angle was suppressed (averaged out) in this table to highlight the effect of radius of curvatures for blade width W2.

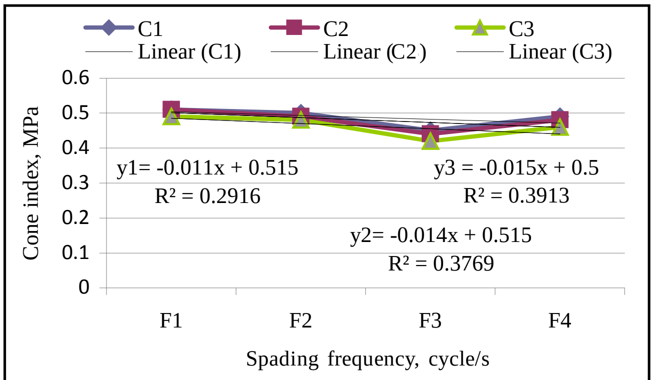

Fig. 8 : Effect of different radius of curvature on soil cone index at blade width W2

The soil pulverized more by blade with radius of curvature C3 as compared to C1 and C2. Hence, soil cone index was lowest with highest spading frequency and with radius of curvature C3, so it resulted into better pulverization and smaller clods. Full face of flat blade touched the soil and detached flat scoop of soil. Curved scoop of soil was detached with curved blades in spading action. Curvature of detached scoop increased with increase in radius of curvature. Scoop of detached soil struck to the cover of spading machine and broke to finer fractions. Curved shape of soil mass broke into finer pie or as compared to flat mass after striking with flat plate.

Effect of radius of curvature on cone index ratio:

The soil pulverized more with blade having radius of curvature C3 as compared to C1 and C2. The results of cone index ratio for different radius of curvatures at blade width W1 and W2. The effect of spading frequency was identical as was observed *i.e.* cone index ratio increased with increase in spading frequency for different

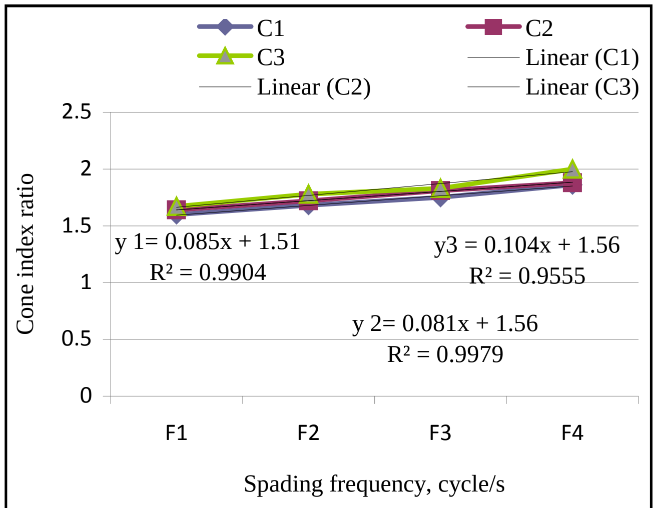

Fig. 9 : Effect of different radius of curvature on soil cone index ratio at blade width W1

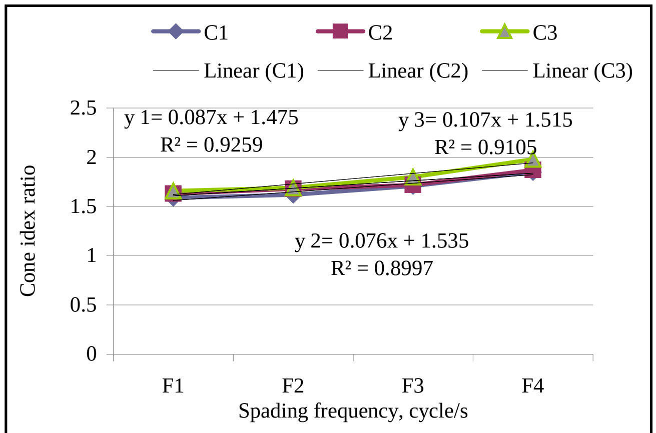

Fig. 10 : Effect of different radius of curvature on soil cone index ratio at blade width W2

radius of curvatures as shown in Fig. 9. For blade width W1 the maximum value of cone index ratio was attained for combination C3F4 (2.00) and minimum for combination C1F1 was 1.60, respectively. The values attained were also regressed and equations have been given in figure itself.

It was evident from Fig. 10 that for blade width W2 cone index ratio was maximum for combination C3F4 (1.98) and it was minimum for combination C1F1 (1.59), respectively.

Hence, cone index ratio was maximum with highest spading frequency studied *i.e.* F4 and with C3 radius of curvature, so it resulted into better pulverization and smaller clods. It could be due to the fact that full face of flat blade touched the soil and detached flat scoop of soil. Curved scoop of soil was detached with curved blades in spading action. Curvature of detached scoop increased with increase in radius of curvature. Scoop of detached soil struck to the cover of spading machine and broke into finer fractions. Curved shape of soil mass broke into finer pie or as compared to flat mass after striking with flat plate. Similar work related to the present investigation was also conducted by Bishnoi *et al.* (2014 a and b); Bishnoi *et al.* (2014) and Winkelblech (1961).

Conclusion :

– Weighted mean clod size decreased with increase in radius of curvature and spading frequency. In blade width W1 and W2 minimum weighted mean clod size was found (1.71mm) for W1 (10 cm) blade width and C3 (30 cm) radius of curvature at F4 (4.62) spading frequency. Maximum weighted mean clod size was 14.15mm observed for blade W2 (15 cm) wide and C1 (Flat) radius of curvature at F1(1.85 cycles/s) spading frequency.

– Soil bulk density decreased with increase in radius of curvature and spading frequency, increased with increase in blade width. Minimum soil bulk density was 1.24 Mg/m^3 observed for W1 (10 cm) wide blade with C3 (30 cm) radius of curvature at F4 (4.62 cycles/s) spading frequency. Maximum soil bulk density was 1.37 Mg/m^3 observed for W2 (15 cm) wide blade with C1 (Flat) radius of curvature at F1 (1.85 cycles/s) spading frequency.

– Cone index decreased with increase in spading frequency, radius of curvature but increased with increase in blade width. Minimum cone index was 0.43 MPa observed for W1 (10 cm) wide blade with C3 (30 cm) radius of curvature at F4 (4.62 cycles/s) spading frequency. Maximum cone index was 0.51 Mg/m^3 observed for W2 (15 cm) wide blade with C1 (Flat) radius of curvature at F1 (1.85 cycles/s) spading frequency.

– Cone index ratio increased with increase in spading frequency, radius of curvature, but decreased with increase in blade width. Minimum cone index ratio was 1.59 observed for W2 (15 cm) wide blade with C1 (Flat) radius of curvature at F1 (1.85 cycles/s) spading frequency. Maximum cone index ratio was 1.51 observed for W1 (10 cm) wide blade with C3 (30 cm) radius of curvature at F4 (4.67 cycles/s) spading frequency.

– These results indicated that weighted mean clod size, bulk density, cone index and cone index ratio was concerned best with the combination C3F4W1.

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