Effect of spade angle and spading frequency of spading machine on specific soil resistance and pulverization

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Abstract: The effect of spade angle and spading frequency on various dependent variables, i.e. specific soil resistance encountered, energy consumed per unit volume of soil moved, weighted mean clod size, soil bulk density, soil cone index and cone index ratio were studied. The experiments were conducted in soil having 15.7% clay, 53.6% silt, and 30.7% sand. During experimentation, moisture content of soil was maintained between 13% and 14%. The spade angles used were A1 (0°), A2 (15°) and A3 (30°). Four levels of bite lengths viz. 4, 6, 8 and 10 cm at travel speed of 18.47 cm s^{-1} were selected for the study. These corresponded to four levels of spading frequencies namely F1 (1.85 cycles s^{-1}), F2 (2.31 cycles s^{-1}), F3 (3.08 cycles s^{-1}) and F4 (4.62 cycles s^{-1}). The spading frequency was determined by dividing the travel speed by the bite length. The dependent variables decreased with increase in spade angle and spading frequency. However, the cone index ratio increased with increase in spade angle and spading frequency. Therefore, for maximum pulverization and optimal specific soil resistance and energy consumption, larger spade angle and higher spading frequency were considered to be desirable.

Keywords: spading machine, spade angle, spading frequency, degree of pulverization

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1 Introduction

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 (Manfred, 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 (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

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effect of spade angle and spading frequency on performance of spading machine.

2 Materials and methods

2.1 Location

The study was conducted in the department of Farm Machinery and Power Engineering, PAU Ludhiana, Punjab, India.

2.2 Soil

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

2.3 Experimental design and methods

Factorial Randomized Block Design was selected to conduct the experiments and to analyse the effect of the study variables. Each experiment was replicated thrice. The effect on various dependent variables i.e. specific soil resistance encountered, energy consumed per unit volume of soil moved, weighted mean clod size, soil bulk density, soil cone index and cone index ratio (Ratio of sum of area of Cone index initial divided by sum of area of cone index after treatment) had been studied. There were three spade angles (Figure 1), two spade widths and four spading frequencies with three replications: A1 (straight), A2 (15°) and A3 (30°); W1 (10 cm) and W2 (15 cm); F1 (1.85 cycles s^{-1}), F2 (2.31 cycless^{-1}), F3 (3.08 cycles s^{-1}) and F4 (4.62 cycles s^{-1}).

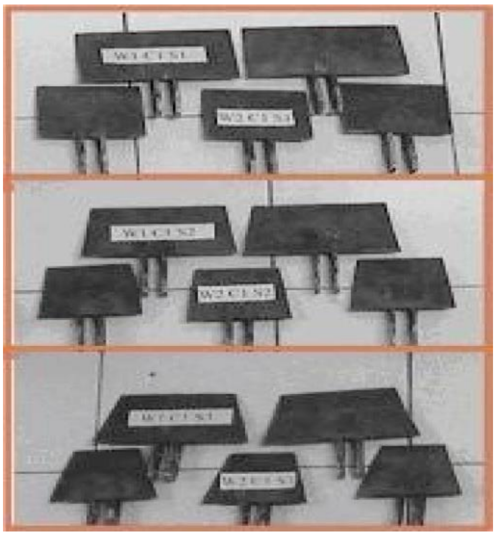

Figure 1 Views of spading blades used for the study

2.4 Soil bulk density

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

2.5 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.

$$MMD = 1/W\,(D_1A + D_2B + D_3C + \ldots + D_nN)$$

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*.

2.6 Soil cone index

Soil cone index was determined (Figure 2) 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. Cone size was 315 mm^2 base area and 21 mm diameter (Anon, 2004). Cone penetrometer used model C 1851 and was made by ESS BEE Universal.

Figure 2 Set-up for measuring cone index in soil bin

2.7 Soil moisture content

Soil moisture content was determined gravimetrically. Samples were obtained using core sampler and oven dried at 110±5 ℃ for 24h (Anon, 1973). During experimentation moisture content of soil was maintained between 13% and 14% by adding calculated amount of water in the soil.

2.8 Seed-bed preparation in soil-bin

The field soil was brought from field and filled in the soil bin. The soil was then pulverized by a roto-tiller and compacted by pneumatically pressurised rollers. The compress roller freshly tilled soil with rollers exerting positive pressure on soil. The soil was compacted by two passes of pneumatically pressurized rollers (Figure 3). The soil was first compacted at constant pressure of 0.1 MPa with rollers suspended in air and then soil was compacted at downward pneumatic pressure of 0.1 MPa.

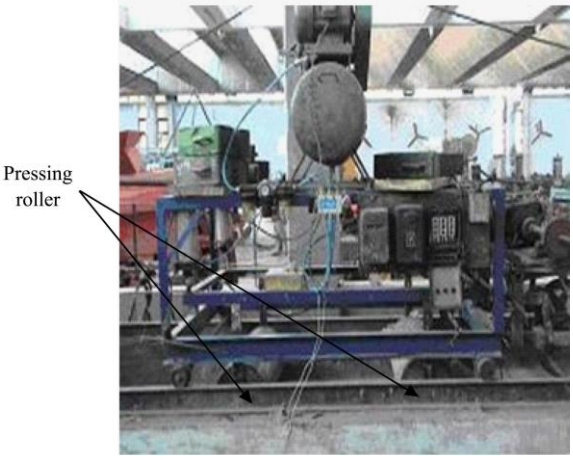

Figure 3 View of compressor, pneumatic cylinders and controls used for tool carriage

2.9 Experimental procedure

A wireless strain gauge type torque transducer mounted on intermediate shaft of tool carriage trolley has been used to measure shaft torque. The torque sensor (strain gauge) was pasted on the intermediate shaft powering the spading machine (Figure 4).

A 9-volt battery, a transmitter and an antenna were strapped on the same shaft. Another magnetic mount receiving antenna was positioned near transmitter within six meters. Before applying each test the receiver unit was set 'ON' and the software was also set 'ON'. Then the carriage of spading blades was run in the soil-bin. The data in tabular form along with the graphical representation was available on monitor of computer and was recorded. The generated table was exported to a spreadsheet and saved as an excel file. Specific soil resistance encountered was determined by dividing the average shaft torque by arm length of spading mechanism and frontal area of blade. Energy consumed per unit volume of soil moved was determined by dividing power to volume of soil moved per bite. Cone index ratio was determined by dividing initial cone index by final cone index. The hypothesis selected for optimization was that the pulverization should be maximum, specific soil resistance and energy expenditure should be optimal. The observations recorded on specific soil resistance encountered, energy consumed per unit volume of soil moved, weighted mean clod size, soil bulk density, soil cone index and cone index ratio were analysed using analysis of variance and conclusions were drawn by testing the significance of difference between various levels/combinations of factor levels. All differences were tested at 5% level of significance.

Figure 4 Torque transducer pasted on shaft and modules, receiver, and computer

3 Results and discussion

The experiments were conducted on soil having 15.7% clay, 53.6% silt and 30.7% sand. During experimentation moisture content of soil was maintained between 13% and 14% (Dry basis). The effect of different spade angles and spading frequencies on various dependent variables, i.e. specific soil resistance encountered, energy consumed per unit volume of soil moved, weighted mean clod size, soil bulk density and soil cone index were found to be inversely related i.e. increase in spade angle caused decrease in various dependent variables.

3.1 Effect of spade angle and spading frequency on specific soil resistance

The effect of spade angle on specific soil resistance was significant at 5% level of significance. The analysis of variance (ANOVA) of specific soil resistance encountered (Table 3) indicated that the effect of blade width, spading frequency and spade angle were significant at 5% level of significance in that order. Further it was revealed from Table 3 that soil tilled by A3 i.e. 30° spade angle had significantly lower specific soil resistance among all the treatments. The effect of spade angle (Table 1 and Table 2) on specific soil resistance was inversely related i.e. as the spade angle increased specific soil resistance decreased. However, the maximum soil resistance was close to 0.14 N cm^{-2} at A1 (straight) and minimum was 0.04 N cm^{-2} at A3 (30°) for blade width W1. It was also evident from the Table 1 that the specific soil resistance decreased with increase in spading frequency for different spade angles. Similarly, maximum specific soil resistance for blade width W2 (Table 2) was 0.20 N cm^{-2} at A1 (straight) while minimum was 0.08 N cm^{-2} at A3 (30°). Hence, it indicated that with increase in spade angle average soil resistance decreased also resulting in better pulverization. It was evident from the Table 2 that for the blade with higher spade angle i.e. A3 (30°) soil failed in tension and the failure plane was progressive, whereas for A1 (straight) and A2 (15°) soil failure was also in tension but was slower in comparison to A3 (30°).

Table 1 Effect of different spade angles and spading frequency on specific soil resistance (N cm^{-2}) at blade width W1

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	0.14	0.11	0.08	0.05
A2	0.13	0.11	0.07	0.05
A3	0.11	0.10	0.06	0.04

Table 2 Effect of different spade anglesand spading frequency on specific soil resistance (N cm^{-2}) at blade width W2

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	0.20	0.17	0.12	0.11
A2	0.18	0.16	0.12	0.09
A3	0.17	0.14	0.11	0.08

Table 3 Analysis of variance foreffect of different spade anglesand spading frequency on specific soil resistance (N cm^{-2})

Source of variation	d.f.	M.S	F-Ratio	CD (5%)	C.V.
A	3	0.24588750E-01	72.96**	0.122996E-01	
B	2	0.22249220E-02	6.60**	0.106517E-01	
AB	6	0.57467570E-04	0.17	NS	
C	1	0.46130260E-01	136.88**	0.869710E-02	
AC	3	0.42253480E-04	0.13	NS	
BC	2	0.58969480E-04	0.17	NS	
ABC	6	0.47814720E-04	0.14	NS	
Error	48	0.33700810E-03			16.42

Specific soil resistance encountered decreased with increase in spading frequency. Since the specific soil resistance encountered was least for spading frequency F4 compared to F1, F2 and F3 so spading frequency F4 was considered better than F1, F2 and F3. Therefore, best combination from specific soil resistance encountered point of view was F4. It was evident that the specific soil resistance encountered was lower for W1 compared to W2 because the failure planes were wide apart in case of bigger blade causing lesser internal fragmentation produced resulting in higher soil resistance (Dogra et al., 2014). Specific soil resistance was the minimum for combination W1F4 but maximum for combination W2F1. Therefore, best combination from specific soil resistance point of view was W1F4 (Dogra et al., 2014). Specific soil resistance encountered decreased with increase in spade angle. Specific soil resistance encountered was minimum (0.08 N cm^{-2}) for A3 and maximum (0.20 N cm^{-2}) for A1. Thus A3 was considered better than A1 and A2. Hence best combination was W1F4A3.

3.2 Effect of spade angle and spading frequency on energy consumed per unit volume of soil moved

Spade angle had significant effect on the energy consumed per unit volume of soil moved in all the treatments at 5% level of significance. Analysis of variance was carried out and presented in Table 6. It was revealed that blade width, spading frequency and spade angle were highly significant in that order affecting the energy consumed per unit volume. It was also observed that the soil tilled with 30° spade angle had significantly lesser energy consumption per unit volume amongst all the treatments. The result with effect of spade angle on energy consumed per unit volume of soil moved has been given in Table 4 and Table 5. It can be seen from these

Tables that as the spade angle increased the energy consumed per unit volume of soil moved decreased. It was also evident that with increase in spading frequency the energy consumed per unit volume of soil moved decreased.

However, the maximum energy consumed per unit volume of soil moved for blade width W1 was close to 97.95 kW sm^{-3} and minimum was 28.78 kW sm^{-3}. Similarly it was evident that for blade width W2 maximum energy consumed per unit volume of soil moved was 138.06 kW sm^{-3} and minimum was 59.81 kW sm^{-3}. Hence, it indicated that increase in spade angle energy consumed per unit volume of soil moved decreased at different combinations. Further it can be observed that with increase in the spade angle energy consumed per unit volume of soil moved during spading action decreased. This is primarily due to the fact that as the spade angle increased, the base width of the blade hitting the soil at first instance was lesser thereby resulting in progressive failure, the reduced cutting force which in turn reduced the overall energy consumption per unit volume of soil moved while causing movement of the soil through spading action. Energy consumed per unit volume decreased with increase in spading frequency. The energy consumed per unit soil moved was least for spading frequency F4 compared to F1, F2 and F3 respectively. Therefore, higher spading frequency F4 was superior to F1, F2 and F3. Energy consumed per unit volume for blade width W1 was lesser and it increased with increase in blade width.

Table 4 Effect of different spade angles and spading frequency on energy consumed (kW sm^{-3}) at blade width W1

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	97.95	79.47	55.10	35.14
A2	88.90	77.51	46.46	32.36
A3	80.76	71.09	41.27	28.78

Table 5 Effect of different spade angles and spading frequency on energy consumed (kW sm^{-3}) at blade width W2

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	138.06	116.84	87.78	76.12
A2	126.87	111.62	84.84	67.14
A3	116.89	98.47	80.41	59.81

Table 6 Analysis of variance foreffect of different spade angles and spading frequency on energy consumed (kW sm^{-3})

Source of variation	d.f.	M.S	F-Ratio	CD (5%)	C.V.
A	3	12323.910	72.97**	8.70731	
B	2	1115.0310	6.60**	7.54075	
AB	6	28.846350	0.17	NS	
C	1	23119.940	136.89**	6.15700	
AC	3	21.243490	0.13	NS	
BC	2	29.635740	0.18	NS	
ABC	6	23.898760	0.06	NS	
Error	48	168.89970	0.14		16.42

Higher energy consumption with bigger blades was caused due to bigger fracture planes. Probable the cracks go much deeper requiring higher energy. Although deeper cracks were preferable but energy consumption was almost 40% more. Therefore, smaller blades W1 appeared to be superior to W2. It was also observed that the soil tilled with A3 had significantly lower energy consumption per unit volume among all the treatments. It meant that with spade angle A3 soil failed in tension and the failure plane was progressive. With spade angle A1 and A2 soil failed in tension but soil failure was slow. This was primarily due to the fact that as the spade angle increased, the base width of the blade hitting the soil at first instance decreased thereby resulting in progressive failure, the reduced cutting force which in turn reduced the overall energy consumed per unit volume of soil moved while causing movement of the soil through spading action. Therefore, higher spade angle A3 was superior to A1 and A2. Therefore, best combination from energy consumption per unit soil moved point of view was W1F4A3.

3.3 Effect of spade angle and spading frequency on weighted mean clod size

The effect of spade angle and spading frequency on weighted mean of clod size was studied. The results and analysis of variance (ANOVA) of weighted mean clod size (Table 9) indicated that the effect of various main variables and their interaction was significant at 5% level of significance. It was evident from Table 7 and Table 8 that with increase in spade angle weighted mean clod size decreased showing better pulverization. Similarly, with increase in spading frequency weighted mean clod size decreased showing better pulverization (Kathirvel et al., 2011). The maximum of weighted mean clod size for blade width W1 was 11.01 mm and minimum was 1.81 mm (Table 7). Similarly for blade width W2 (Table 8) maximum weighted mean clod size was 15.64 mm and minimum was 1.91 mm.

Table 7 Effect of different spade angles and spading frequency on mean clod size at blade width W1

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	11.01	7.07	4.40	2.80
A2	6.37	4.73	3.20	2.03
A3	4.20	4.00	2.65	1.81

Table 8 Effect of different spade angles and spading frequency on mean clod size at blade width W2

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	15.64	11.17	5.55	3.52
A2	11.34	7.75	4.08	2.63
A3	9.46	6.27	3.52	1.91

Table 9 Analysis of variance for effect of different spade angles and spading frequency on mean clod size

Source of variation	d.f.	M.S	F-Ratio	CD (5%)	C.V.
A	3	185.00450	524.70**	0.397836	
B	2	73.673340	208.95**	0.344536	
AB	6	8.7616580	24.85**	0.689071	
C	1	101.92940	289.09**	0.281312	
AC	3	19.205760	54.47**	0.562624	
BC	2	0.40893940	1.16	NS	
ABC	6	0.40230180	1.14	NS	
Error	48	0.35258870			10.39

This signified that with 30° spade angle smaller clods were formed hence better pulverization of soil, as smaller and progressive failure planes resulted in better pulverization. Large spade angle resulted in larger failure planes. For maximum pulverization of soil weighted mean clod size should be the minimum. It was evident that weighted mean clod size decreased with increase in spading frequency. Thus, F4 can be considered best. The weighted mean of clod size was the minimum for smaller blades. Therefore, smaller blades W1 were superior to W2. Similarly it was observed that weighted mean clod size was the maximum for A1 followed by A2 and A3. Thus, A3 was considered to be better. So, the better combination was W1F4A3.

3.4 Effect of spade angle and spading frequency on bulk density

The effect of spade angle on soil bulk density was significant at 5% level of significance. Analysis of variance was carried out and had been presented in Table 12. It was revealed from Table 12 that A3 had significantly lesser soil bulk density than A2 and A1. The effect of spade angle on soil bulk density for blade width W1 indicated that as the spade angle increased the achieved bulk density decreased. The results of effect of spade angle for blade width W1 and W2 have been shown in Table 10 and Table 11. The maximum bulk density achieved was close to 1.36 Mg m^{-3} and minimum was 1.22 Mg m^{-3}. The maximum soil bulk density for blade width W2 was 1.38 Mg m^{-3} and minimum was 1.26 Mg m^{-3}. Hence, it indicated that with increase in spade angle soil bulk density decreased showing better pulverization. The section of blade impacting soil at first instance was smallest for blades having higher spade angles. This resulted in generation of relatively smaller failure planes compared to blades with lower spade angles. Small and progressive failure planes resulted in better pulverization. Thus, soil bulk density was lesser for blades with higher spade angle. Soil bulk density decreased with increase in spading frequency. Soil bulk density was the minimum for F4. The soil bulk density was the minimum for smaller blades. Minimum value of soil bulk density was observed at combination W1F4. Since this was in line with earlier results so it was considered. It was also observed that soil bulk density was the maximum for A1 compared with A2 and A3. Thus, A3 was considered to be better. So the combination W1F4A3 was retained as better combination.

Table 10 Effect of different spade angles and spading frequency on soil bulk density at blade width W1

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	1.36	1.32	1.30	1.28
A2	1.33	1.31	1.28	1.27
A3	1.32	1.29	1.27	1.22

Table 11 Effect of different spade angles and spading frequency on soil bulk density at blade width W2

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	1.38	1.34	1.33	1.30
A2	1.36	1.33	1.31	1.29
A3	1.33	1.31	1.30	1.26

Table 12 Analysis of variance for effect of different spade angles and spading frequency on soil bulk density

Source of variation	d.f.	M.S	F-Ratio	CD (5%)	C.V.
A	3	0.19352380E-01	23.57**	0.191980E-01	
B	2	0.84495540E-02	10.29**	0.166260E-01	
AB	6	0.29457920E-03	0.36	NS	
C	1	0.10965130E-01	13.35**	0.135751E-01	
AC	3	0.34190710E-04	0.04	NS	
BC	2	0.86890530E-04	0.11	NS	
ABC	6	0.17618260E-03	0.21	NS	
Error	48	0.82106070E-03			2.19

3.5 Effect of spade angle and spading frequency on soil cone index

The effect of spade angle and spading frequency on soil cone index was significant at 5% level of significance. The data was statistically analysed and presented in Table 15. The effect of spade angle on soil cone index was indicated that the A3 (30°) could produce finer soil compared to A2 (15°) and A1 (straight), which led to better pulverization of soil. Maximum soil cone index achieved for blade width W1 was close to 0.521 MPa and minimum was 0.398 MPa (Table 13). Similarly, it was evident (Table 14) that for blade width W2 maximum soil cone index was 0.523 MPa and minimum was 0.403 MPa. Hence, it indicated that increase in spade angle soil cone index decreased showing better pulverization. The soil mass with bigger clods have higher cone index because intergranular air space is not proportionate to clod size. This happens because after removing the chunk of soil mass the spading machine strikes it with cover and the soil mass gets broken into smaller clods. These clods settled on the soil bed. In this settling process initially the clods break to finer fractions after striking the ground surface. The clods which follow get broken into relatively bigger sizes. Since these are fractured they tend to fill the available space. Thus, the larger clods moved to the surface while the smaller clods concentrated in the deeper layers (Winkelblech, 1961). It was observed that the soil cone index decreased with increase in spading frequency. Soil cone index was the minimum with spading frequency F4 compared with other spading frequencies. Therefore, F4 was considered to be better than spading frequencies F1, F2 and F3. Soil cone index was lesser for W1 compared with W2. Therefore, W1 was considered better than W2.

Table 13 Effect of different spade angles and spading frequency on cone index at blade width W1

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	0.521	0.499	0.476	0.460
A2	0.497	0.477	0.465	0.443
A3	0.484	0.453	0.433	0.398

Table 14 Effect of different spade angles and spading frequency on cone index at blade width W2

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	0.523	0.508	0.489	0.462
A2	0.498	0.490	0.474	0.444
A3	0.493	0.478	0.447	0.403

Table 15 Analysis of variance for effect of different spade angles and spading frequency on cone index

Source of variation	d.f.	M.S	F-Ratio	CD (5%)	C.V.
A	3	0.15285070E-01	64.44**	0.103187E-01	
B	2	0.11553450E-01	48.71**	0.893629E-02	
AB	6	0.37617080E-03	1.59	NS	
C	1	0.13520980E-02	5.70**	0.729645E-02	
AC	3	0.18395220E-03	0.78	NS	
BC	2	0.10087690E-03	0.43	NS	
ABC	6	0.18227300E-04	0.08	NS	
Error	48	0.2371999E0-03			3.27

Also it was found that soil cone index was the maximum for A1 compared with A2 and A3. Performance was better with A3. So, A3 was considered to be the best. So, the combination W1F4A3 was considered best. This matches with earlier choice of weighted mean clod size and soil bulk density, therefore combination W1F4A3 considered the best for maximum pulverization.

3.6 Effect of spade angle and spading frequency on cone index ratio

The effect of spade angle and spading frequency on soil cone index ratio was significant at 5% level of significance. The data on cone index ratio was statistically analysed and had been presented in Table 18. It was observed that the soil which was tilled by 30° spade angle had significantly lowest soil cone index among all the treatments. The effect of spade angle on cone index ratio indicated that the A3 (30°) produced finer soil compared to A2 (15°) and A1 (0°), which indicated better pulverization of soil. It was evident from Table 13 that as the spade angle increased the cone index ratio increased. However, the maximum (Table 16) cone index ratio achieved for blade width W1 was 2.08 and minimum was 1.57. It was evident (Table 17) that for blade width W2 maximum cone index ratio was 2.06 and minimum was 1.56.

Table 16 Effect of different spade angles and spading frequency on cone index ratio at blade width W1

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	1.57	1.64	1.73	1.79
A2	1.65	1.72	1.76	1.87
A3	1.69	1.81	1.90	2.08

Table 17 Effect of different spade angles and spading frequency on cone index ratio at blade width W2

Spade angle (Degree)	Spading frequency, cycle s^{-1}			
	F1	F2	F3	F4
A1	1.56	1.61	1.68	1.79
A2	1.65	1.67	1.72	1.86
A3	1.67	1.71	1.84	2.06

Table 18 Analysis of variance for effect of different spade angles and spading frequency on cone index ratio

Source of variation	d.f.	M.S	F-Ratio	CD (5%)	C.V.
A	3	0.25540900	74.49**	0.392325E-01	
B	2	0.18212130	53.11**	0.339763E-01	
AB	6	0.11279340E-01	3.29**	0.679527E-01	
C	1	0.21014740E-01	6.13**	0.277416E-01	
AC	3	0.34207930E-02	1.00	NS	
BC	2	0.17403550E-02	0.51	NS	
ABC	6	0.21899120E-03	0.06	NS	
Error	48	0.34288840E-02			3.34

Hence, it indicated that with increase in spade angle cone index ratio increased showing better pulverization. The soil mass with bigger clods had higher cone index because inter-granular air space is not proportionate to clod size. Hence, the cone index ratio with bigger clods was lower than smaller clods.

Two hypotheses for optimization were selected, firstly the pulverization should be maximum, secondly specific soil resistance and energy consumption should be optimal. In whole study of all the factors like spading frequency, spade angle and blade width in relation to weighted mean clod size, soil bulk density and soil cone index from point of view of pulverization as well as specific soil resistance encountered and energy required per unit mechanical manipulation of soil the best combination was W1F4A3. The optimum values of independent parameters have been given in Table 19.

Table 19 Optimum values of independent parameters

Parameters	Values
Blade width (W), cm	10
Spading frequency (F), cycles s^{-1}	4.62
Spade angle (A), degree	30

4 Conclusions

Specific soil resistance, energy consumed, weighted mean clod size, soil bulk density and cone index decreased with increase in spading frequency and spade angle, but increased with increase in blade width. Minimum specific soil resistance, energy consumed, weighted mean clod size, soil bulk density and cone index were encountered (observed) for W1 (10 cm) wide blade with A3 (30°) spade angle and at spading frequency of F4 (4.62 cycles s^{-1}) and maximum for W2 (15 cm) wide blade with straight spade angle (0°) and at spading frequency of F1 (1.85 cycles s^{-1}). Cone index ratio increased with increase in spading frequency and spade angle, but decreased with increase in blade width. Minimum cone index ratio was observed for 15 cm wide blade with straight spade angle (0°) at spading frequency of F1 (1.85 cycles s^{-1}). Maximum cone index ratio was observed for W1 (10 cm) wide blade with A3 (30°) spade angle at spading frequency of F4 (4.62 cycles s^{-1}). These results indicated that maximum pulverization and optimal specific soil resistance encountered and energy consumption best with the combination W1F4A3.

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