Performance evaluation of cone penetrometer device for measuring the subsoil compaction in mulched plots

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Abstract: Soil exhibits layers of extreme compaction from both natural causes and wheel traffic. These compaction layers impede root growth, thereby reducing the plants capacity to obtain water during drought. Subsoil tillage is a remedy for adverse soil compaction that results in improved conditions for crop growth. Mechanical disturbance of subsoil increases water holding capacity and reduces impedance to root penetration. Vertical mulching is a technique that can be used to partially alleviate soil compaction within the critical root zones of deep rooted crops. A study was conducted by placing raw and composted coir pith using a two row subsoil coir pith mulching machine in three different soil depths (250, 350, and 450 mm) at the three application rates of 15 t/ha, 20 t/ha, and 25 t/ha and the effect of soil strength was investigated. The experiment was conducted for a rainfed cotton crop. The soil strength profile was recorded in all the treatments. The cone penetrometer resistance was measured for each increment of 10 mm and recorded manually from a digital force indicator during maturity stages of crop in all the treatment plots. The cone penetrometer resistance was measured directly on the row and the cone index was computed. Deep placement of mulch reduced the soil strength as compared to shallow placement. The lower soil strength (0.5 kPa to 0.8 kPa) in the loosened and mulched zone provided an impedance free zone for the root to proliferate. The rapid increase in cone index values at depths immediately below the respective depth of placement (250, 350 and 450 mm) of raw and composted coir pith mulch indicated that the existence of undisturbed soil profile below the mulched zone which could be potential limiting factor for root development.

Keywords: soil strength, raw coir pith, composted coir pith, cone penetrometer, cone index, subsoil compaction
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1 Introduction

The soil tends to recompact and requires periodic subsoiling due to natural reconsolidation and surface forces of uncontrolled traffic. One method proposed to lengthen the time between periodic subsoiling is to incorporate some type of non-soil, foreign material into the subsoiled zone to keep the soil particles from cohering to each other and to provide extra pore space to improve water infiltration and storage. Presence of organic mulch material in the subsoil could also make the subsoil biologically active and enhance root growth into subsoil layers. Subsoil placement of mulch would prevent it from getting dispersed during subsequent tillage operations. Subsoiling is one part of a crop production system. Operating economics, crop residue

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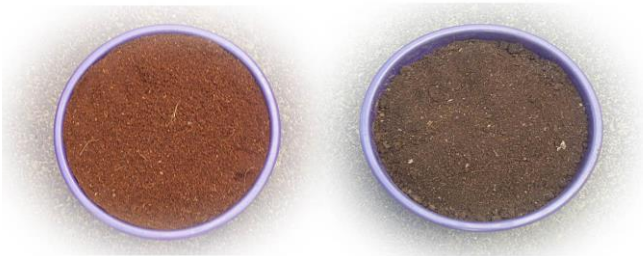
management, soil physical properties, and crop response are the factors to be weighed in managing this component of the overall system. Subsoiling is often used to combat soil compaction and reduce soil strength to levels that allow for root development and growth[1-3]. This tillage process provides increased rooting depth to withstand short term drought conditions prevalent during the crop growing season. The depth of annual subsoiling is between 300 and 500 mm. The depth of tillage is often chosen based on the average needs of the soil and capability of the tractor and implement.

Coir pith is an underutilized by-product of coconut. The use of coir pith waste in agriculture as a rooting medium, mulch, and soil conditioner to improve soil drainage has proved beneficial[4]. Accumulation of coir pith has always been a problem as its excess production contaminates water sources in coir producing regions. The utilization of coir pith as a soil conditioner and a plant growing medium paved the way for the economic utilization of the potentially valuable waste product into an environment friendly product of world demand, thus solving the waste disposal problem faced by the coir producers[5]. The spongy structure of coir pith facilitates retention of water. It has the stability for conditioning of farm soil for retention of moisture for mulching and as a receptacle for slow release of added nutrients to the crops. Raw coir pith decomposes in the soil very slowly as its pentosan lignin ratio is less than 0.5, which is minimum required for slow decomposition of organic matter in the soil[6]. Coir pith is an excellent mulch material in all kinds of soil. The unique property of raw coir pith to hold 7-8 times its weight of moisture helps in improving the moisture and nutrient availability of the root zone. Coir pith is highly resistant against biological degradation. Subsoil mulching can have long term effects, compared to surface incorporation[7-9].

Application of coir pith as subsoil mulch could prevent subsoil from recompaction and also improve the soil structure. Subsoil mulching with coir pith is a new concept. Deep loosening of soil and placement of coir pith in subsoil layers as mulch directly below the crop rows would improve the root zone which would not recompact during subsequent years. One of the suggested applications of coir pith was to use it as an ingredient to improve the manurial value of soil[10]. But the actual manurial value of the raw coir pith is low compared to other standard manures. Coir pith compost is used as a source of plant nutrition, growing medium, and as a carrier material for bio-fertilizer. The nutrient value in terms of N, P, and K content and C: N ratio is better in composted coir pith than raw coir pith[10]. Hence, three levels of subsoil mulch materials were selected as raw coir pith (Figure 1a), composted coir pith (Figure 1b), and no mulch for the investigation.



a. Raw coir pith (M1) b. Composted coir pith (M2)

Figure 1 Mulch materials used for the experiments

The forces encountered by the tillage tools have been investigated by many designs of dynamometers under laboratory and field conditions. Osburn et al.[11] developed an electronic hand-operated recording penetrometer. Rathore et al.[12] observed that the penetrometer resistance at different periods (50, 70, 90, and 110 days) of crop growth for mustard and chickpea varied among 1.58-4.54 MPa and 1.66-3.26 MPa, respectively, for mulched plots, whereas in no mulched plot, the penetrometer resistance varied among 2.39-5.37 MPa for mustard and 2.51-5.42 MPa for chickpea. Schonning and Rasmussen[13] evaluated the subsoiled plot three years after compaction and reported that in sandy soil, subsoiling significantly improved the penetration resistance from about 300 to 450 mm deep when compared to the sandy loam soil.

Manohar Jesudas[14] developed a tractor operated cone penetrometer for measuring soil resistance. The penetration force was sensed by a hydraulic dynamometer. The dynamometer was connected to two pressure gauges mounted on a panel to indicate pressure in the range of

0-28 and 0-70 kg/cm^2. Busscher et al.[15] investigated the effect of subsoiling in loamy sand (soil compacted by traffic) on yield of wheat and soybean and reported that the yield was increased in wheat by 1.5-1.7 Mg/ha for each 0.1 MPa decrease in cone index (CI) from 1.55 MPa to 0.85 MPa due to subsoiling. The soybean yield increase was from 1.1 Mg/ha to 1.8 Mg/ha per 0.1 MPa decrease from 2.1 MPa to 1.0 MPa. Penetration resistance or cone index (penetration force per unit cross-sectional area of the cone base, in MPa) is a more useful measure of soil strength. The critical value of 2 MPa or 2.5 MPa has been proposed as a critical value for root penetration[16,17]. Information is needed on the interactive effect of different mulch materials, placement depth of mulch, and mulch application rate on soil strength. Hence, this investigation was aimed at assessing the effect of subsoil mulching (with and without mulching) on the development of mechanical resistance of cotton crop under rainfed conditions.

2 Materials and methods

Soil cone penetrometers are useful for quick determination of soil strength and levels of soil compaction. The penetration resistance as measured by different designs of cone penetrometers has been extensively used by researchers such as hand-operated recording penetrometers that do not require a second person and can be inserted continuously into the soil[18,19] to quantify initial soil conditions and degree of loosening obtained by deep tillage studies. The commercially available penetrometers cannot be used when penetration resistance exceeds the weight of the operator. They can be used only up to a depth of 100-180 mm in hard soil. Moreover, it is difficult to maintain a constant rate of penetration. Hence, a tractor -mounted cone penetrometer was developed with load cell type force measurement system for recording the soil resistance. The specifications of the tractor operated cone penetrometer are shown in Table 1 and Figure 2. The cone penetrometer has five main components including mounting frame, penetrometer column, drive mechanism, load cell (300 kg) and digital display force indicator, and power source.

Table 1 Specification of tractor operated cone penetrometer

Particulars	Specifications
Mounting frame (L × B × H), mm^3	2500 × 75 × 40
Hitch	Category I or Category II
Diameter of the hollow steel tube, mm	50
Thickness of the hollow steel tube, mm	3
Power source	64 Watt DC motor
Diameter of the aluminum tube, mm	40
Thickness of the aluminum tube, mm	3
Standard cone base area, mm^2	320
Standard cone Apex angle, (°)	30
Diameter of the solid stem , mm	16
Load cell capacity, kg	300
Force indicator	Digital display
Maximum depth of operation, mm	600
Speed of Penetration, mm s^{-1}	3

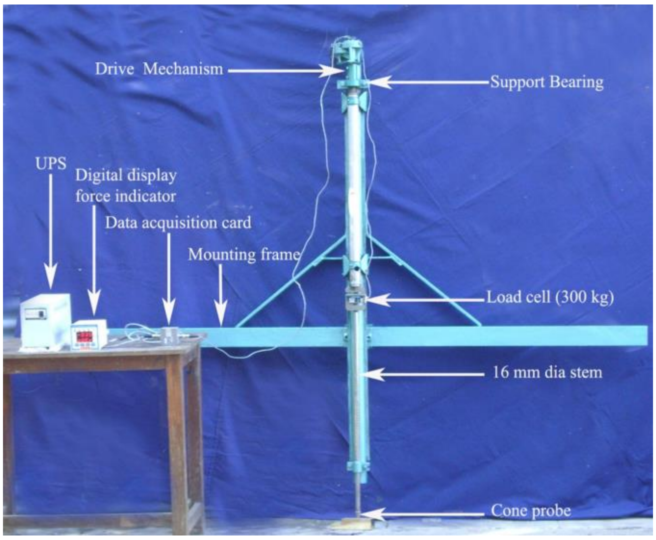


Figure 2 Tractor operated cone penetrometer- Idle view

The mounting frame consists of 2 500 mm long channel section of 75 mm × 40 mm steel. It is provided with a standard three-point hitch bracket. Provision is made to hitch the frame to Category I or Category II hitch system of tractors. Adjustable check chains are provided to restrain the upward motion of tractor lower links during operation of the penetrometer. The penetrometer column is made of hollow steel tube of diameter 50 mm having a 3 mm thickness. The column supports the bearing housing, bottom guide bushing and motor mounting flange at the top. A 64 Watt DC motor is mounted on the top of the penetrometer column, and the motor is powered by the tractor battery of 12 V DC. The penetrometer column is fixed vertically with the mounting frame with the help of clamps. The mounting clamps are welded to the penetrometer column. Both sides of the penetrometer column are provided with channels of size 12 mm × 12 mm for guiding the penetrometer. The clamp can be moved along the length of the mounting frame and can be locked at any desired position.

The penetrometer is actuated by a screw and nut mechanism powered by the DC motor. The speed of the output shaft of the drive unit varies from 45 r/min to 54 r/min depending on the applied load. The nut is fixed to one end of the aluminum tube of 40 mm diameter and 3 mm thick. The other end of the tube is fitted with load cell. The screw rod is mounted on the bearing at its upper end and a nylon bushing at its lower end to ensure proper alignment of the screw rod with the tube. The screw nut is shielded in the aluminum tube. The length of the aluminum pipe is 600 mm. The aluminum pipe along with the screw nut mechanism slides vertically up and down along the channel provided on the two sides of the penetrometer column. A two-way switch is mounted on the tractor to control the up and downward movement of the screw nut assembly. One end of the load cell is connected to the screw nut mechanism, which is actuated up and down by means of two way switch. The penetrometer is fitted with the standard cone conforming to ASAE specifications (S313.1). The cone has a base area of 320 mm^2 and an apex angle of 30^o. The cone is machined out of stainless steel and polished. It is mounted to a solid stem of diameter 16 mm. The upper end of the stem is fitted with the load cell.

2.1 Function of cone penetrometer

The penetrometer is attached to the tractor and transported to the field; the lower links are arrested by tightening the check chain in order to prevent movement of penetrometer. The penetrometer is positioned in the trial field between the plants and between the rows and then clamped. Prior to field measurement, the load cell of the cone penetrometer is calibrated in the laboratory by addition of known weights. When the DC motor is switched on, the standard cone in the solid stem penetrates into the soil. In the solid stem of the cone penetrometer markings are made from 0 - 500 mm (with a spacing of 10 mm) from bottom to top for measuring the depth. When a load on the probe is sensed, contact with the soil surface is assumed to have been made and data are recorded from that point onwards. The resistance offered to the penetrometer of the cone in the soil is sensed by the load cell and the value is displayed in the load cell indicator. After the maximum depth of 500 mm is achieved, the cone is extracted from the soil and moved to the next sampling location. The observations are recorded from 0 to 500 mm depth and cone is retracted by reversing the drive motor. The operational view of tractor operated cone penetrometer between the plants and between the rows for measurement of soil strength in the experimental plot is shown in Figure 3.

Figure 3 Tractor operated cone penetrometer

2.2 Construction of two row prototype subsoil coir pith mulcher

The functional components of tractor operated two row subsoil coir pith mulcher are main frame, chisel plough assembly, feed hoppers, coir pith feed hopper, fertilizer hopper, auger feed metering mechanism for coir pith, orifice and agitator type metering mechanism for fertilizer, agitator for coir pith, ground wheel assembly and power transmission system for placing the raw and composted coir pith at selected depths (D_1, D_2, D_3) and selected application rates (A_1, A_2, A_3).

2.3 Field evaluation

Field evaluation was conducted to assess the interactive effect of selected levels of variables (mulch material, depth of placement, and application rate) on cone index. The experiment was laid out in field No. 36 E of Eastern block of Tamil Nadu Agricultural University, Coimbatore, which is situated at 11^o north latitude and

77° east longitude at an elevation of 498 meters above the mean sea level. The experimental field is a heavy black clay loam soil. The experiment was conducted for a rainfed cotton crop. The variety of crop selected for rainfed cultivation was MCU 12. The special features of this variety are medium staple, resistant to bacterial blight, field tolerant to rhizocotania and alternaria. The duration of crop is 150 days.

2.4 Experimental design

A total number of 57 experiments with three replications were conducted in the experimental fields with selected levels of variables. The size of the each plot was 3 m × 3 m. In the experiment mulch material includes M_1 (Raw coir pith) and M_2 (Composted coir pith); application rate includes A_1 (15 t/ha), A_2 (20 t/ ha) and A_3 (25 t/ha); depth of placement includes D_1 (150-250 mm, Shallow depth), D_2 (250-350 mm, Medium depth) and D_3 (350-450 mm, Deeper depth); total number of treatments is 57 = 2 × 3 × 3 × 3 + 3 Plots (Control: no mulch).

2.5 Evaluation parameters

The influence of the selected levels of variables on soil strength in terms of cone penetrometer resistance was evaluated.

2.6 Soil strength profile

The soil strength profile was recorded in all the treatments. The tractor mounted-digital electrically driven cone penetrometer described earlier was used. The penetrometer resistance was measured for each increment of 10 mm and recorded manually from the digital force indicator during boll formation and maturity stages of cotton crop in all the treatment plots. For each treatment, penetrometer resistance readings were directly recorded on the rows and the cone penetrometer resistance was computed from the recorded values. The cone index values (CI) were calculated using the following expression and expressed as MPa:

Base area of the cone (A) = 320 mm^2

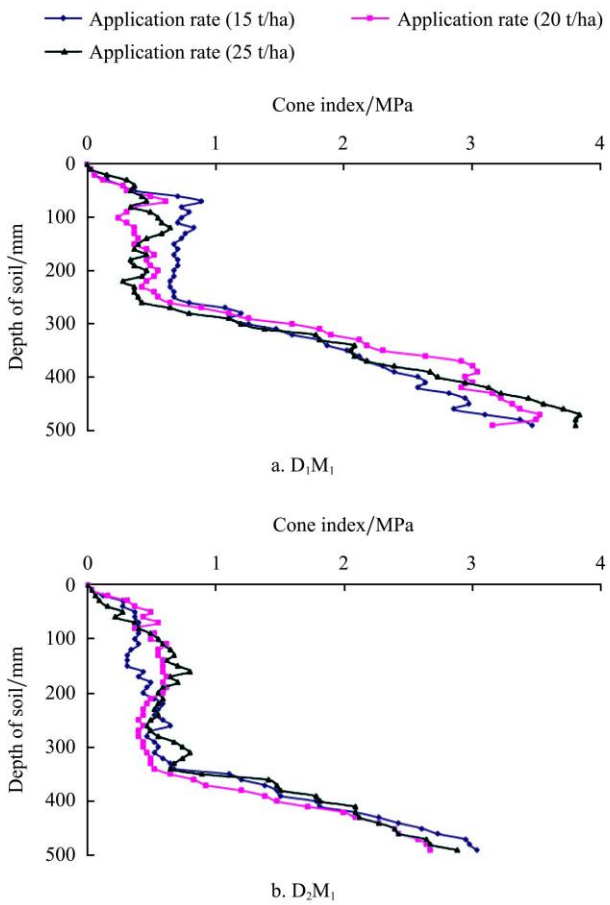
Force (F) = Cone penetrometer reading (kg) ×9.81 (N)

$$\text{Cone index (CI, MPa)} = \frac{F}{A} \times 0.000001 \quad (1)$$

In the experiment, the values were recorded for all treatments of investigation. The effects of selected levels of variables on the evaluation parameters were analyzed by using a statistical tool. The experiment data were analyzed using randomized block design (RBD). The statistical package IRRISTAT was used to analyze the data. This was done to obtain the necessary analysis of variance of mean and interaction of the selected variables *viz.*, mulch material (M), application rate of subsoil mulch (A), and depth of placement of subsoil mulch (D) on soil strength.

3 Results and discussion

The soil strength profile was recorded in all the treatment plots using the tractor mounted electrical driven cone penetrometer. The penetrometer resistance was measured for each increment of 10 mm and recorded manually from the digital force indicator during maturity stages of crop in all the treatment plots and the mean CI was computed. The cone penetrometer resistance profiles upto a depth of 500 mm at 10 mm intervals in relation to application rate and depth placement of raw and composted coir pith is shown in Figures 4 and 5, respectively.



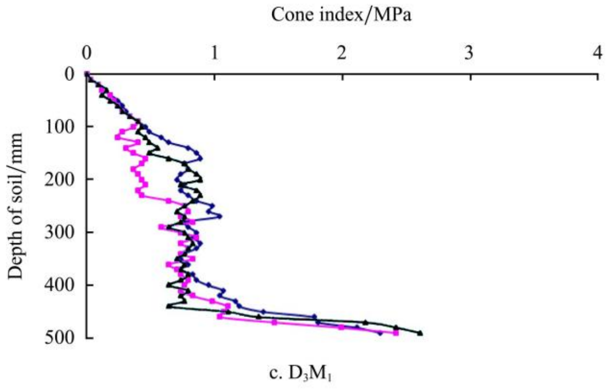


Figure 4 Effect of application rate of raw coir pith mulch (M_1) on cone index with depth

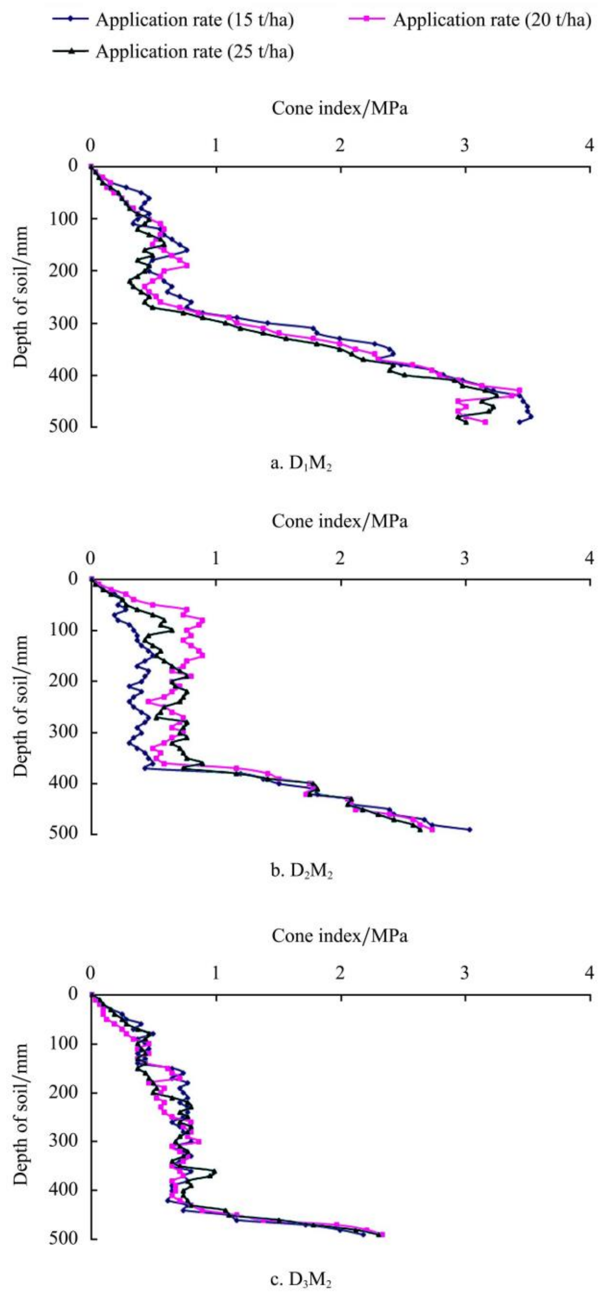


Figure 5 Effect of application rate of composted coir pith mulch (M_2) on cone index with depth

The effect of deep loosening and placement of mulch was clearly reflected in the Figures 4 and 5. The soil strength was significantly different upto the depth of placement of mulch as compared to subsoil layers. Deeper mulching was clearly shown to reduce soil strength upto deeper layers as compared to shallow mulching. The average soil strength in the loosened and mulched zone was between 0.5 kPa and 0.8 kPa and this was expected to provide an impedance free zone for the root to proliferate. It is noticed that there was no significant variation in CI values between 15 (A_1), 20 (A_2) and 25 (A_3) t/ha application rates of raw and composted coir pith mulch. Hence, to investigate the effect of mulch material and depth of placement on cone index, the values of selected levels of application rates were pooled and the mean values were arrived. The effect of pooled values of application rate of raw and composted coir pith on soil strength profile in treatment plots from 0 to 500 mm depth of placement of mulch is depicted in Figures 6 and 7, respectively. The statistical analysis of

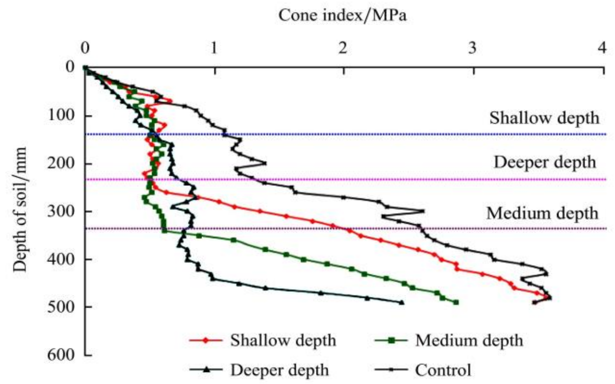


Figure 6 Cone index profile averaged for three levels of application rate of raw coir pith mulch (M_1) in the experimental field

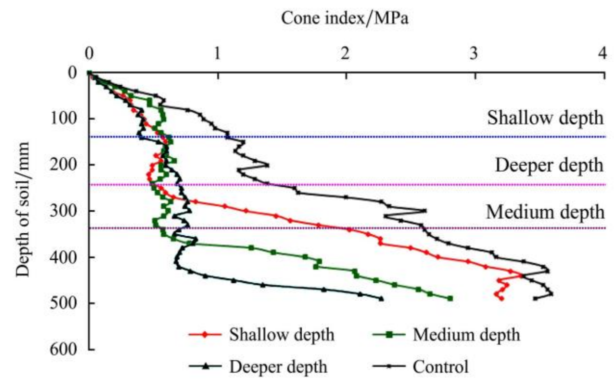


Figure 7 Cone index profile averaged for three levels of application rate of composted coir pith mulch (M_2) in the experimental field

the data was performed to assess the significance of the variables *viz.*, mulch material (M), application rate of mulch (A) and depth of placement (D) on penetrometer resistance of soil (CI, MPa). The analysis of variance for CI (MPa) is furnished in Table 2.

Table 2 ANOVA for cone index in experimental field

S.L No.	SV	Degree of freedom	SS	MS	F value
1	Treatments	26	17.729721	0.681912	1305.9083**
2	Replication	2	0.210314	0.105157	201.3824
3	Depth of placement (D)	2	2.441736	1.220868	2338.0447**
4	Mulch material (M)	2	13.858773	6.929386	13270.2444**
5	Application rate (A)	2	0.003706	0.001853	3.5488*
6	D × M	4	1.222901	0.305725	585.4847**
7	M × A	4	0.029886	0.007472	14.3086**
8	D × A	4	0.064190	0.016048	30.7321**
9	D × M × A	8	0.108528	0.013566	25.9799**
10	Error	52	0.027153	0.000522	1.0000

Note: ** means significant at 1% level; * means significant at 5% level; ns means not significant; cv (coefficient of variation) = 7.78%; SV means Source of Variation; SS means Sum of Squares, and MS means Mean Square.

The results of ANOVA indicated that there was significant difference among the treatments. The individual effect of the variables *viz.*, mulch material (M) and depth of placement (D) were significant at 1% level of probability whereas the application rate of mulch (A) was significant at 5% level of probability which confirmed the earlier discussion. In the treatment effect, the order of significance was highest for mulch material (M) followed by depth of placement (D) and application rate of mulch (A) on soil penetrometer resistance (CI, MPa). This confirmed the above discussion that the depth of placement (D) had a significant effect on cone index than application rate. The interaction effect of D × M, M × A, D × A, D × M × A, were significant at 1% level of probability.

Soil cone index is an empirical measure of soil strength and widely used for assessment of compacting and loosening effects of implements. It can also be used to assess root growth and penetration. Hence the relationship between soil strength and root length in raw and composted coir pith mulched treatments is shown in Figure 8 and the relationship between soil strength and root spread in raw and composted coir pith mulched treatments is shown in Figure 9.

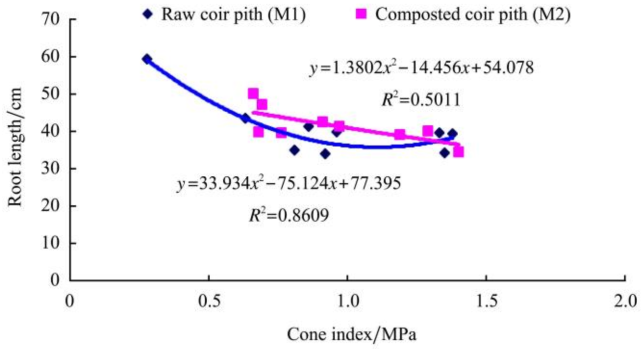


Figure 8 Relationship between soil strength (cone index) and the root length in raw (M_1) and composted coir pith mulched treatments (M_2)

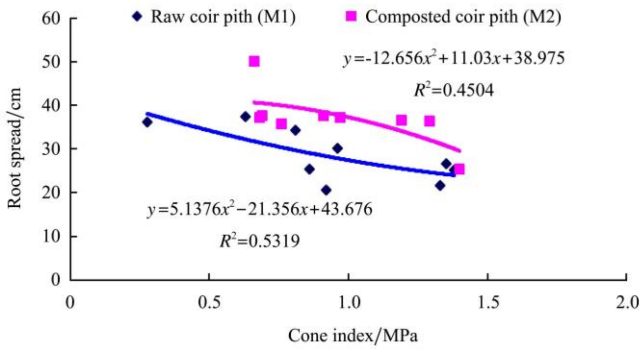


Figure 9 Relationship between soil strength (cone index) and the root spread in raw (M_1) and composted coir pith mulched treatments (M_2)

The relationship between soil strength and root volume in raw and composted coir pith mulched treatments is shown in Figure 10. From the figures 8, 9, and 10 it is inferred that the root length, root spread and root volume increased with decrease in soil strength. Root length, root spread and root volume decreased with increase in soil strength which might be due to the restriction of root growth at higher soil strength. No significant treatment effect on root length and root spread was observed between the raw coir pith and composted coir pith mulch treatments. The higher the cone index, the higher amount of energy expended by the root was to widen the soil pores.

The relationship between soil strength and crop yield in raw and composted coir pith mulched treatments is shown in Figure 11. It is important to note that relatively high yields were achieved under low CI of soil, because roots were able to grow rapidly into the subsoil and use the residual subsoil water. The beneficial effect of mulch on root proliferation was most likely through the effect of mulch on soil water content, where the higher soil water contents under the mulch treatments resulted in lower soil strength and thus reflected in yield.

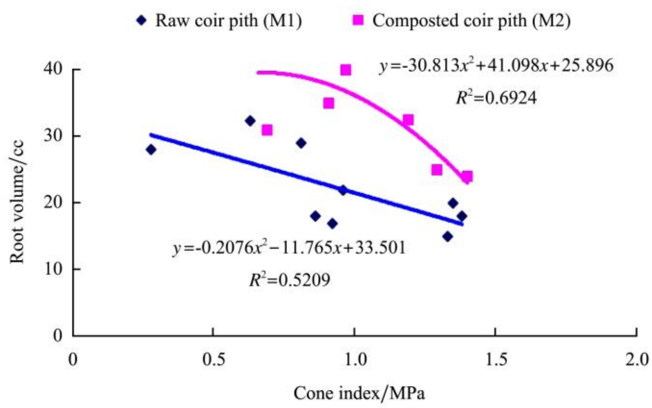


Figure 10 Relationship between soil strength (cone index) and the root volume in raw (M_1) and composted coir pith mulched treatments (M_2)

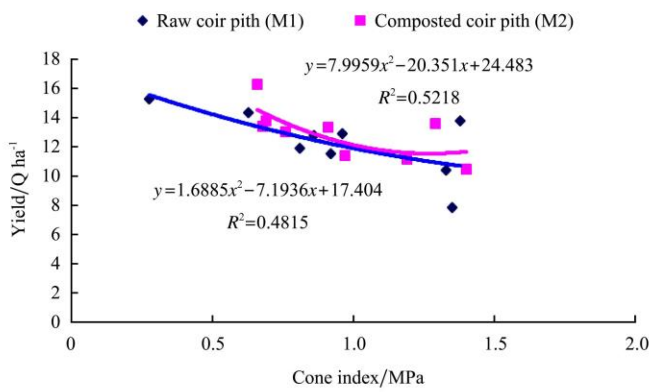


Figure 11 Relationship between soil strength (cone index) and the crop yield in raw (M_1) and composted coir pith mulched treatments (M_2)

4 Conclusions

The interactive effect of mulch material, application rate of mulch and depth of placement was investigated in terms of cone index. Deep placement of mulch reduced the soil strength as compared to shallow placement. The lower soil strength (0.5 to 0.8 kPa) in the loosened and mulched zone provided an impedance free zone for the root to proliferate. The rapid increase in CI at depths immediately below the respective depth of placement (250 mm, 350 mm and 450 mm) of raw and composted coir pith mulch indicated that the existence of undisturbed soil profile below the mulched zone could be potential limiting factor for root development. The root length, root spread and root volume increased with decrease in soil strength. No significant treatment effect on root length and root spread was observed between the raw coir pith and composted coir pith mulch treatments. Relatively higher yields were achieved in the treatment with lower CI of soil under the mulch treatments.

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